Ruins Stabilization in the Southwestern United States

RUINS STABILIZATION

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The Mission Church, Tumacacori National Monument, Tumacacori, Arizona. Comprehensive stabilization, repair, and partial restoration of the Mission Church was performed in 1921 by Frank Pinkley. Lower portions of the columns and bases of the facade were restored in 1945. Since that time, all efforts by the National Park Service have been directed to preserving existing original construction. Replacement plaster, where required to cover eroded original lime plaster and adobe brick surfaces, consists of a tinted cement-lime-sand mortar employed with a bonding agent.

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RUINS STABILIZATION IN THE SOUTHWESTERN UNITED STATES

Compiled by

ROLAND VON S. RICHERT and
R. GORDON VIVIAN

National Park Service

U. S. Department of the Interior
Washington 1974

Richard Nixon
PRESIDENT OF THE UNITED STATES

Rogers C. B. Morton, Secretary
UNITED STATES DEPARTMENT OF THE INTERIOR

Ronald H. Walker, Director
NATIONAL PARK SERVICE

As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park, and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources." The Department works to assure the wisest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.

This publication is one of a series of research studies devoted to specialized topics which have been explored in connection with the various areas in the National Park System. It is printed at the Government Printing Office, and may be purchased from the Superintendent of Documents, Washington, D. C. 20402. Price $0.00

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Foreword

On May 13, 1971, President Richard Nixon signed Executive Order 11593, entitled "Protection and Enhancement of the Cultural Environment," a far-reaching document charging all departments and agencies of the Federal Government with responsibility for preserving the Nation's historic properties. This book, compiled by two authorities on the stabilization of archeological ruins, is issued to further the purposes of that Executive Order.

The President's order makes the Secretary of the Interior responsible for developing professional guidelines and providing Federal, State, and local agencies with professional advice and technical information to assist in safeguarding these antiquities. The National Park Service provides the Department of the Interior with the staff and professional services to meet these responsibilities.

ROGERS C. B. MORTON
Secretary of the Interior

White House Ruin, Canyon de Chelly National Monument, Chinle, Arizona. The main occupation took place within the period A.D. 1000-1300. The White House was so-named for the conspicuous white plaster which covers a long wall in the upper, cave portion of the ruin. The remaining architecture has been stabilized by repairing, grouting, respalling and capping of walls and, additionally, by sub-soil intrusion grouting. The magnificent, water-stained, red sandstone cliff rises a sheer 600 to 700 feet above the canyon floor.

Preface

From the time the first American set foot on this continent, at least 150 centuries ago, his concern for shelter required a substantial portion of his energy and imagination. Much of what we know about him is reflected in his constructions, whether flimsy huts in the open or in caves, elaborate stone dwellings, or religious structures. When the first Europeans and later immigrants arrived, they too sought to modify the environment, bringing with them the building traditions of their fathers, thereby contributing to the richness and extraordinary diversity of architecture in the United States.

Many of us have visited our Federal, State and local parks and landmarks where the remains of such prehistoric and historic structures are being preserved. During these visits, we have been enriched and moved by the spirit of our distant predecessors reflected in their will to build and exercise their artistic talents. We may also have seen the effect of time's unrelenting assault on man's creations. Wind, rain, heat and cold destroy the sturdiest of structures. Add to these fire, plant growth, bacteria, insects, rodents, and even man himself, and the forces that eventually turn great edifices to rubble are better understood.

Although the forces that destroy cannot be controlled everywhere and at all times, we can insure that future generations will experience some of the richness of this archeological and historic heritage. The contents of this book provide a partial answer. It tells us how to go about the business of preservation in a straightforward way. It assumes that time heals no wounds where the works of man are left to the vicissitudes of nature. And it assumes that there will always be men willing to learn the fundamentals of ruins stabilization, which often combines hard labor with the application of the most recent advances in chemistry and construction technology.

This guide was compiled by Roland Von S. Richert and the late R. Gordon Vivian, both with many years of experience in the stabilization of ruins for the National Park Service. The work will be of great value to historians, archeologists, and architects. For the student of ruins stabilization, and for construction and maintenance personnel of local, State, and Federal agencies, it should prove indispensable.

RONALD H. WALKER, *Director*
National Park Service

Publications in Archeology*

Archeological Research Series

1. Archeology of the Bynum Mounds, Mississippi (PB 177 061).**
2. Archeological Excavations in Mesa Verde National Park, Colorado, 1950 (PB 177 062).**
3. Archeology of the Funeral Mound, Ocmulgee National Monument, Georgia (PB 177 063).**
4. Archeological Excavations at Jamestown, Virginia (PB 177 064).**
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7A. The Archeological Survey of Wetherill Mesa, Mesa Verde National Park, Colorado (Wetherill Mesa Studies).
7B. Environment of Mesa Verde, Colorado (Wetherill Mesa Studies).
7C. Big Juniper House, Mesa Verde National Park, Colorado (Wetherill Mesa Studies).
7D. Mug House, Mesa Verde National Park, Colorado (Wetherill Mesa Studies).

8. Excavations in the 17th-Century Jumano Pueblo, Gran Quivira, New Mexico.
9. Excavations at Tse-ta'a, Canyon de Chelly National Monument, Arizona.
10. Ruins Stabilization in the Southwestern United States.

Anthropological Papers

1. An Introduction to Middle Missouri Archeology.
2. Like-a-Fishhook Village and Fort Berthold, Garrison Reservoir, North Dakota.

*Concurrent with the establishment of the Office of Professional Publications, National Park Service, the name *Archeological Research Series* has been changed to *Publications in Archeology*. The numbering of the volumes will not change. The series entitled *Anthropological Papers* is discontinued.

**These publications are no longer available from the Superintendent of Documents. They may be ordered by title (and parenthetical code number) by writing to: Clearinghouse, U. S. Department of Commerce, Springfield, Virginia 22151. These reports are available in two forms: microfiche at 95 cents per document, or paper copy at $6.00 per volume, prepaid.

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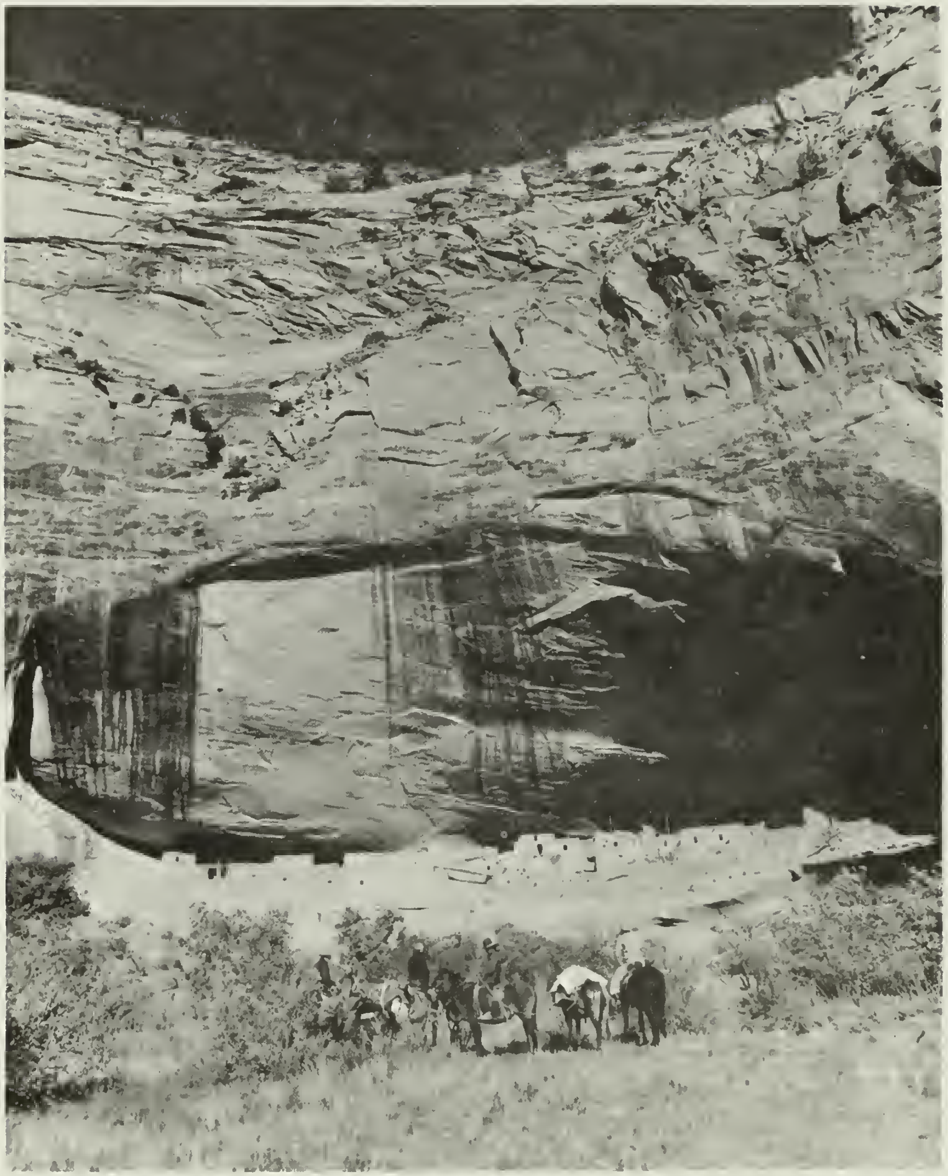


Keet Seel Ruin, Navajo National Monument, Arizona. Occupied intermittently through Pueblo I and Pueblo II periods (A.D. 1250-1286), the ruin was first excavated and stabilized in 1934 by a Civil Works Administration crew under the sponsorship of the Museum of Northern Arizona. Additional work by the National Park Service in 1958 and 1970 corrected numerous weaknesses, and recorded areas of the 1934 research not previously documented. Several types of wall construction are evident, including wattle and daub, masonry, vertical post-reinforced and horizontal post-reinforced.

1 Introduction

This book is a guide to the methods, materials and techniques employed in the stabilization and maintenance of prehistoric and historic structures in a ruinous condition. It is designed especially for construction and maintenance personnel of local, State and Federal agencies charged with the care of land on which there are historic structures worthy of preservation in an "as is" condition. The publication is an outgrowth of a very early ruins stabilization manual written by the late R. Gordon Vivian in 1949 for the National Park Service, and revised in 1962.

The interests served by the two earlier manuals were confined largely to a few specialists of the National Park Service whose duties involved the preservation and maintenance of prehistoric and historic structures. Today, however, a greatly expanded program of preserving cultural properties on a nationwide scale has prompted the need for disseminating guidelines on a much broader base. It should be made abundantly clear that Mr. Vivian's original work is so basic and fundamental that much of it remains intact. Most sections were revised or amplified, and new ones were added as required.

The present edition incorporates important new material reflecting not only the development of ruins stabilization practices, but the urgent need for getting this information from Federal into State and regional channels where it may serve a useful purpose for all who attempt to preserve historic structures. While emphasis is given to definitions, principles, and standards, considerable effort is made to describe the process of stabilizing a given structure, and to evaluate the effectiveness and durability of the measures employed. This manual is concerned primarily with ruins stabilization in the southwest United States, although many problems and techniques discussed herein are applicable in other climates and regions.

The users of this book are encouraged to read another National Park Service publication, entitled *Recording Historic Buildings* (Washington, D. C., 1970) compiled by Harley J. McKee. As McKee stated so aptly in his work, "Only a productive partnership between Federal, State, and local governments, and private individual initiative can assure the adequate recording and successful preservation of our great national patrimony of historic architecture."

HISTORY

The ruins stabilization program of the National Park Service is concerned with the preservation of historic and prehistoric architectural remains. The legal bases are derived from five general laws passed by the Congress of the United States: the Antiquities Act of 1906, the Act of 1916 establishing the National Park Service, the Historic Sites Act of 1935, the National Historic Preservation Act of 1966, and the National Environmental Policy Act of 1969.

General policies under which the program functions were formulated by the Advisory

Board on National Parks, Historic Sites, Buildings and Monuments in 1938, by the Director's Committee on Ruins Stabilization in 1940, and by the *Handbook for Ruins Stabilization*, Part 2, Field Methods, 1962, codified and brought up to date in a *Compilation of the Administrative Policies for the Historical Areas of the National Park System*, revised, 1968.

The purposes with which the ruins stabilization program of the National Park Service is now concerned, and which will continue in the future, are five-fold: 1) the actual work of field crews preserving sites scattered throughout the Service, involving a wide range of structures; 2) the compilation of a complete inventory of archeological and historic structures, and the development, from this, of long-range priorities to cover the maintenance of stabilized sites and the stabilization of others, particularly those in National Park Service areas of increasing visitation and need for research and interpretation; 3) improvement of technology and the use of Space Age plastics and synthetics with emphasis on the preservation of adobe structures; 4) coordination with other units of the Service concerned with the combined excavation-stabilization of interpretive sites, and, wherever possible, further the development of techniques for preserving objects *in situ* and furnishings in museums; and 5) cooperation with other Federal, State, and local agencies by providing them with information and expertise on professional methods of preservation.

The beginnings of Federal involvement in ruins stabilization can be traced back to 1889 when a $2,000 memorial to Congress provided for the stabilization and repair of Casa Grande Ruins near Coolidge, Ariz. Three years later, in June 1892, President Benjamin Harrison signed an executive order recommended by the Secretary of the Interior reserving Casa Grande Ruins and 480 surrounding acres for permanent protection because of its archeological value. Thus the first national archeological reservation in U. S. history was established, preceded by the first ruins stabilization attempts (Lee, 1970, p. 20). Other pioneering stabilization and repair jobs were performed at Chaco Canyon, Canyon de Chelly, Mesa Verde, Tuzigoot and Wupatki, all of which will be mentioned later in this volume.

Recognizing the need to devise means of preserving sites which were rapidly deteriorating under his charge, Frank Pinkley, Superintendent of the former Southwestern National Monuments, Coolidge, Ariz., organized a Mobile Ruins Stabilization Unit in 1937 with a field station at Chaco Canyon National Monument. It was originally set up as a program of the Civilian Conservation Corps by inter-bureau agreement of the National Park Service and the Bureau of Indian Affairs. The National Park Service furnished materials, equipment, and supervision, and the Navajo Agency supplied their camp and a crew of 25 Indian CCC enrollees. An archeologist-foreman and an engineer-foreman supervised. The goal of the Indian mobile unit was to move from area to area among the 14 southwestern archeological and historic monuments, accomplishing emergency, comprehensive, and maintenance stabilization.

As a result of economic retrenchment on a national scale, the Navajo Agency was forced to reduce enrollee strength from 25 to 20 in 1938, and to 10 on July 1, 1940. The unit was disbanded in April of 1942 for the duration of World War II, and was reactivated in October of 1946. Since the latter date, funds for its operation have been provided through the Maintenance and Rehabilitation Account of the National Park Service. Labor continues to be recruited on a WAE (when actually employed) basis, largely from the Navajos, all of whom are qualified by previous training and experience in stabilization. In fact, one or two of the older crew members are former CCC enrollees, while the younger members are "second generation," their fathers having been employed in the Mobile Unit before them. Native patience, artisanship, and resourcefulness, coupled with adaptation to isolated locations under camp conditions, have earned for the Navajo first choice as members of specialized field crews. Their employment is consonant with our National policy of assisting minority groups, and of providing gainful and useful work for

people living in economically depressed areas.

Significantly, employment has not been confined to the Navajo. In recent years, other minority groups, including the Apaches and Spanish-Americans, have been attracted to the program. The San Carlos Apache have been employed on an archeological project at Gila Cliff Dwellings in New Mexico, and on the stabilization of Besh-Ba-Gowah, a city-owned ruin dating in the 14th century A. D., near Globe, Ariz. A deep and abiding dedication to the preservation of mission architecture, combined with a unique skill in working with adobe by the all-Spanish-American crew was largely responsible for the excellent work at the important site of Pecos National Monument in New Mexico.

Work during the formative years of the Mobile Unit's history was concentrated at two or three of the huge surface ruins of Chaco Canyon and at the large West Ruin, Aztec. Stabilization in those early years was accomplished without blueprints or manuals, the work consisting of a unique combination of art, archeology, and a building science in its infancy. Numerous thorny problems involving control of erosion by capillary moisture, repair of wall breaks, support, and realignment, were new and without precedent. Standardized and proven remedial measures were unknown. Wherever possible, standard building procedures were employed, but in many instances untried techniques had to be devised and the results observed and analyzed with the passage of time. Because of obvious structural differences between prehistoric and modern buildings, stabilization has sometimes resulted in a compromise between sound building practice and an attempt at authenticity of appearance.

Clear and complete records were maintained for each project from the beginning of the Mobile Unit's work in 1937. Standardized record sheets were designed and used for each room or unit, together with photographic pages showing both the general conditions and important details of the site. The major objectives were to set down in permanent form the condition of the structure prior to stabilization, and to record stabilization measures taken, including new construction. Thus, a stabilization record evolved into a structural history of a site or an architectural unit of that site. Field notes were maintained as a daily log. Photographs, recorded observations, experiments, special reports and job unit reports were amassed over the years, all of which proved valuable for present and future work. Eventually the repair jobs which were similar in many sites became standardized, involving the same proven technique or group of techniques. More than three decades of periodic inspections of earlier work permitted reliable evaluations as to success or failure and, usually, the reasons therefore. Moreover, based on previous performance standards, it was possible to estimate rather closely the costs of various proposed projects in terms of measured wall areas and quantities, and the material and labor required for stabilization. This data and experience resulted in the formulation and evaluation of stabilization techniques and materials which provide a sound basis for the discipline of preserving prehistoric architectural remains.

The ruins stabilization program of the National Park Service is now carried on at its Archeological Center in Tucson in cooperation with the University of Arizona. The program represents an activity within the Division of Cultural Properities Conservation of the Center, and is an integral part of the Center's operation. A permanent staff of four full time employees are engaged in stabilization work throughout the year. During the summer months, from 40 to 60 temporary employees, including graduate students in anthropology, are organized into crews and are sent to the field.

National Park Service archeology is unique in a number of ways. It approaches the task from a comprehensive viewpoint and embraces research, preservation, and interpretation—a program tailored to the mission of the Service. National Park Service project archeoloy, institutional archeology, and ruins stabilization all benefit from a cooperative approach. Experience has shown that where the Service project archeologist and an institutional archeologist from a university work hand-in-hand to further the

goals of the ruins stabilization program, excellent and durable results are usually obtained. There is absolutely no reason for conflict among government, university, or privately endowed institutions in the allied fields of archeology and stabilization, provided standards and aims are clearly established and implemented on a cooperative basis. Moreover, as funds become available, National Park Service archeologists and historians increase their cooperation with other Federal and State agencies, as well as with local organizations and civic groups. Stabilization requires the expertise of archeologists, architects, engineers, manufacturers, material suppliers, and labor. Each group provides distinct talents which should be sought for every project.

DEFINITIONS

For purposes of discussion in this guidebook, a historic structure is considered to be a work of man, either prehistoric or historic, consciously created to serve some form of human activity. A historic structure, by nature or design, is usually immovable. Besides buildings of various kinds, the term includes works such as dams, canals, bridges, stockades, forts and associated earthworks serving a similar purpose, Indian mounds, gardens, roads, mill races and ponds. By definition, ruins are classified as historic structures and will be accorded treatment as described under the term *stabilization.* It is emphasized that in this volume we are dealing with structures or, more usually, with mere remnants of structures in various stages of deterioration.

In professional circles, the words *preservation, restoration, reconstruction* and *stabilization* frequently stir up a war of semantics. It is small wonder that the layman has difficulty in distinguishing the meanings of these terms. Both within and outside the National Park Service, there is a growing consensus that these words logically come under the broader, all-inclusive phrase "conservation of our nation's non-renewable historic resources." Our definitions of preservation, restoration, reconstruction and stabilization are:

Preservation

Preservation, used architecturally, refers to the stabilization of a structure in its existing form by preventing further change or deterioration. Preservation, since it takes the structure as found, does not relate to a specific period in time and is the most authentic treatment of a historic structure (Bullock, 1966, p. 1, and *Compilation of the Administrative Policies for Historical Areas of the National Park System* (1968, p. 21).

Restoration

Restoration means the process of accurately recovering, by removal of later work and the replacement of missing original work, the form and details of a structure or part of a structure, together with its setting, as it appeared at some period in time. The value of a restoration is measured by its authenticity.

Reconstruction

Reconstruction refers to the re-creation of a building by new construction. Although re-creating the form and details of a vanished structure should be based on all the historical, archeological, and architectural data available, very often the evidence is far from complete, thus detracting from both the accuracy and intellectual integrity of the reconstruction.

Stabilization

Stabilization involves those construction methods, materials, and techniques used to minimize the deterioration of a structure, thereby accomplishing the objective of preservation. Hence, the preservation procedures and techniques designed to arrest further deterioration of ruins are encompassed by the phrase *ruins stabilization.*

Ruins Stabilization

Ruins on unexcavated sites should be stabilized only to that extent which is necessary to preserve them for further investigation. Sites other than those excavated in advance of unavoidable modern construction should not be excavated until adequate provisions have been made to stabilize ruins as they are exposed. In cases where ruins are too fragile for direct visitor

contact, or where deterioration would result from sustained contact, public use should be strictly limited or prohibited. The deliberate creation of ruins out of whole structures by the owner, whether at local, State or Federal levels, is contrary to currently accepted environmental and esthetic principles. Such practices are theatrical, unauthentic, and fraudulent, serving only to deceive the public.

Comprehensive ruins stabilization involves careful planning to place a prehistoric or historic structure in a sound structural condition, and to preserve its appearance immediately following excavation and study. Usually this is the final action taken in prehistoric sites intended for interpretation and visitor-use.

Comprehensive ruins stabilization usually follows closely upon the heels of excavation, and requires the use of evidence from the excavation and other documents. Most comprehensive stabilization requires some archeological excavation, either as a part of the stabilization project, or as a separate but closely related project of interpretive research.

Appearance is a major consideration of comprehensive ruins stabilization. Every effort is made to satisfy the requirements of stability and appearance. It is permissible to patch holes which will approximate the original materials. It is permissible to realign walls, returning them to their original positions, to use force to push them back into plumb position, or to change them from their existing alignment. Parts or elements of structures may be replaced or reset in their original position. This might include resetting part of a fallen wall or resetting a dislodged beam. Original material or newer materials may be substituted for missing parts of a structure. A variety of techniques may be employed in the reinforcement of walls or foundation; internal structural reinforcement members may be built into a wall and concealed, or external ties may be used if these provide the best solution.

Comprehensive ruins stabilization differs from restoration-reconstruction, in that no attempt is made in the former process to restore the structure to its complete, in-use appearance. The surviving original, plus the fallen or displaced elements revealed in the archeo-historical record, limit the extent to which the structure may be returned to its original appearance. The replaced or repaired elements must be readily distinguishable upon close scrutiny, but their appearance should match that of the original and not be apparent to the casual observer.

An excellent definition of stabilization is incorporated in the International Charter for the Conservation and Restoration of Monuments and Sites. It appears in the "Decisions and Resolutions of the International Congress of the Architects and Technicians of Historic Monuments," *Venice Charter* (1964). It is quoted in its entirety, with italics supplied, indicating the passage which appropriately describes "ruins stabilization" as applied in the United States.

> EXCAVATIONS
>
> Article 15. Excavations should be carried out in accordance with scientific standards and the recommendation defining international principles to be applied in the case of archeological excavation adopted by UNESCO in 1956.
>
> Ruins must be maintained and measures necessary for the permanent conservation and protection of architectural features and objects must be taken to facilitate the understanding of the monument and to reveal it without ever distorting its meaning.
>
> *All reconstruction work should however be ruled out* a priori. *Only anastylosis, that is to say, the reassembling of existing but dismembered parts can be permitted. The material used for integration should always be recognizable and its use should be the least that will ensure the conservation of a monument and the reinstatement of its form.*

Two additional terms deserve mention. *Related stabilization* includes those measures taken in proximity to the structure for its prolonged preservation. The work must contribute to the stability of the structure and not detract unduly from its appearance. Typical examples of related sta-

bilization projects include the walkway within the council chamber at Ocmulgee, the river diversion devices in the vicinity of White House and Antelope House at Canyon de Chelly, and of Pueblo del Arroyo in Chaco Canyon, the retaining wall in front of the Lower Ruin at Tonto, the deep interceptor drainage line and surface dike at Aztec Ruins, and the protective roof of Casa Grande.

After a structure has been stabilized and prepared for public view, it is considered to be in maintenance status. Sufficient annual funding should be programmed for *maintenance stabilization* whereby systematic inspections can be made to check and repair minor erosion from natural and human forces before the structural integrity of the building is threatened. In addition to the routine of cleaning up wind-blown or visitor-thrown debris, weed control, renewal of walking surfaces, and the cleaning of drains, maintenance stabilization includes the renewing of wall plaster, repointing wall joints, and resetting loose or missing masonry elements. Maintenance defined simply is the routine, recurring work that is necessary to keep prehistoric and historic structures in such a condition that they may be used for their intended purpose and designed capacity. It includes the replacement, overhaul, or reprocessing of worn and deteriorated materials. Attempts should be made to keep the structure in the same condition as it was when acquired, or when the responsibility for its maintenance was assumed following stabilization. Ideally, maintenance personnel who are responsible for the structure also will have participated in the stabilization. If this is not possible, the maintenance personnel should be given special training and orientation.

2 Problems

The problem of stabilizing and maintaining historic sites is one that has almost as many ramifications as there are individual structures. Since this book originated from experiences derived in the Southwestern United States, including Arizona, New Mexico, Colorado, Utah, southeastern California, and western Texas, it is concerned largely with pre-Columbian masonry structures, post-1540 A.D. adobe structures, and, to a lesser extent, with monolithic soil structures, sometimes termed *pise* or rammed earth. In the following discussion of Southwestern archeological sites, we will deal first with the problems of structural faults and inherent weaknesses. We will then look briefly into the forces that have contributed to their deterioration. Some understanding of these faults and forces is necessary before they can be effectively counteracted.

Anyone who sets out to stabilize a prehistoric structure will find that he has two conflicting objectives. The first of these is the requirement of authenticity in preserving irregular and relatively primitive construction. Equally important is the need for permanence, the requirement of any sound building practice.

STRUCTURAL FAULTS

The prehistoric mason was a progressive architect and builder for his day. The Anasazi progressed in a short span of 300 years—10 or 12 generations—from pit houses to multistoried buildings of 400 and 500 rooms. In each period and area, he followed a rather set pattern of plan and construction circumscribed by the limitation of local materials. At any one time a village consisted of an accretion of ruined, decaying, remodeled, and new units. Rooms were often built on the partially razed wall of older structures and on loose fill. Foundations were often narrower than the walls they supported. Walls were rarely bonded at corners or other junctions.

The materials encountered in almost all possible combinations include abundant soil mortar with spalls stuck in the surface, soil mortar with unshaped or slightly shaped stone, facing at stone-to-stone contact, dry masonry, wattlework, and jacal or pole and mud construction. Soil structures were always laid in a plastic condition—in thick courses at Casa Grande, in plastic loaves in turtleback walls of Pueblo I sites, and in roughly squared plastic blocks in ruins on the Animas and at some late prehistoric Rio Grande pueblos.

The following list summarizes the structural faults most commonly encountered:

1. No foundations (fig. 1).
2. Foundations narrower than the walls they support (fig. 2).
3. Construction over loose and unconsolidated fill.
4. Long spans over openings supported by extremely small lintels.
5. Lack of bond at wall junctures.
6. Lack of headers or ties through walls where there is more than one width of stone.
7. The incorporation of large horizontal wood beams in masonry walls (fig. 3).

FIGURE 1. Settling caused by lack of foundations and unstable fill. Bond between stone and soil mortar is poor. Holes are caused by decay or theft of wood members. (Antelope House Ruin, Canyon de Chelly National Monument, Ariz.)

8. The inclusion in walls, at ceiling height, of horizontal areas of bark, splints, rods, and other ceiling materials.

A number of post-1540 A.D. buildings at Pecos, Tumacacori, Fort Davis, Fort Union, Fort Bowie, and the early 20th-Century Spanish-American residences at Big Bend National Park, were constructed of adobe bricks. Where either the adobe or lime mortar plaster had weathered from wall core surfaces, and the roofs were either removed or deteriorated, ruins range in appearance from no vestiges at all, through low mounds, to imposing wall remnants rising in excess of 30 feet above present ground surface. While structural faults were not as common as in the pre-Columbian structures (the result of advanced methods of construction) a number of factors, not the least of which was the type of building material, resulted in more rapid deterioration from causes mentioned below.

WEATHERING

The breakdown of an abandoned structure follows a rather set pattern. First, wind- and waterborne material is deposited on the floor. This deposition continues until it is covered by collapse of roofing and dislodged sections of wall. Once the roofing is gone, stability of walls is threatened, and the generally poor materials and faulty construction become particularly vulnerable to the elements. Moisture from snow and rain melt out the mud mortar; thin unbonded facing is separated by frost action; rotting of wood parts

such as beams, lintels, or ceiling inclusions results in unsupported overlying masonry; pressure from fallen material dislocates remaining walls, and the accumulated debris ponds surface water which, in turn, subjects basal areas to moisture penetration and erosion.

Depending primarily on the type of construction and location of the structure, these forces proceed at different rates. In small open units which are usually thin-walled structures, the downward erosion is most rapid, and large areas of collapsed wall are rarely found. Within large sites of heavy construction and in protected sites this downward erosion is less rapid. Collapsed sections of large wall areas are more often encountered, the result of horizontal erosion at base and ceiling lines, and the decay of wood members.

The action of natural forces outside the structure also has an important bearing on preservation. Weathering of wall bases and soft sandstone outcrops on which pueblo ruins stand has become serious at Hovenweep and in sections of Wupatki. Important sites in caves are deteriorating at Navajo and Canyon de Chelly National Monuments, the result of wind and water having removed supporting fill and portions of bedrock. Within historic times, about 75 percent of one 40-room site in Chaco Canyon has been lost to arroyo-cutting. As opposed to erosion, the deposition of wind- and water-borne materials adjacent to sites can sufficiently alter the topography to destroy natural drainage and cause flooding.

Walls of *pise* construction, such as those at Casa Grande, and adobe brick construction at Tumacacori, present special problems. Natural weathering is particularly severe where the protective roofing is gone and the foundation is not waterproof. Erosion proceeds from all sides, especially from the tops and bottoms of the walls. Starting at the bottom of the wall, soil moisture rises by capillary action, carrying soluble salts which are deposited at the evaporation line just above existing ground level. A large proportion of these salts are hygroscopic, and are composed of chlorides, carbonates, and nitrates of calcium and magnesium. This concentration of salts acts in two ways to destroy the character of the adobe at the evaporation line. Crystallization shatters the adobe, causing continual shedding of surface particles. Also, concentration of salts above an unknown limit results in chemical destruction of the cohesive elements of the material and in its further disintegration. (Adobe workers are well aware of this process and do not use soils from alkali bearing areas for their bricks. Furthermore, they dislike the use of water with a strong salt content.) As this concentration increases, the salts, as hygroscopic agents, attract moisture from the air, espe-

FIGURE 2. Aboriginal construction often left narrow strips at ceiling line. This wall is much wider at the top than in the center. (Room 27, north wall, Pueblo del Arroyo Ruin, Chaco Canyon National Monument, N. M.)

cially during periods of high humidity, and the process of erosion is accelerated. Erosion of this type results in troughing which, in time, may cut entirely through the wall.

Erosion at the tops and sides of an adobe wall is caused by rain, hail, wind and melting snow which result in vertical rivulets, fissures, and a general thinning and eventual melting of the adobe.

HUMAN AND ANIMAL DISTURBANCE

Unprotected sites have been vandalized for centuries. Such activity is more destructive of prehistoric buildings than is generally supposed. In the first place, the prehistoric inhabitants periodically tore down old houses to reuse the timbers and building stone. Neil Judd makes note of prehistoric vandalism at Pueblo Bonito, at a time following its abandonment, by groups seeking precious objects of turquoise, jet, and shell (Judd, 1964). Similar plundering and salvaging continued into the historic period. Early settlers in the Chaco speak of the Navajo removing wagonloads of timbers from Chettro Kettle for firewood. These same settlers did so themselves, and also used stone from the Chaco Canyon ruins.

FIGURE 3. The inclusion of heavy timbers within cored-type walls was a usual practice of prehistoric builders. Collapse of walls from flood damage at Chettro Kettle exposed 300 logs similar to those above. (Chettro Kettle Ruin, Chaco Canyon National Monument, N. M.)

Adolph Bandelier, the famous Swiss anthropologist, undertook his first important field project in American archeology—an exploration of the Southwest, in August of 1880. He began with a preliminary study of Pecos. In his report (1883, p. 42) there appears this shocking account of the 18th-century mission church of Pecos:

> Mrs. Kozlowski (wife of a Polish gentleman, living two miles south on the arroyo) informed me that in 1858, when she came to her present home with her husband, the roof of the [adobe brick] church was still in existence. Her husband tore it down, and used it for building outhouses; he also attempted to dig out the cornerstone, but failed. In general the vandalism committed in this venerable relic of antiquity defies all description...all the beams of the old structure are quaintly...carved...much scroll work terminating them. Most of this was taken away, chipped into uncouth boxes, and sold, to be scattered everywhere. Not content with this, treasure hunters...have recklessly and ruthlessly disturbed the abodes of the dead.

Prior to acquisition by the National Park Service, a number of military posts either suffered severe depredations or were fortuitously preserved, at least in part, following abandonment by the Army. Fort Bowie was turned over to the Department of the Interior in 1894 and the land was auctioned off to ranchers. Subsequently, local residents cannibalized the buildings for construction materials. Erosion quickly set in, and the post soon fell into ruins. Some of the major buildings at Fort Davis and Fort Larned were occupied by civilians who kept the structures in repair, occasionally remodeling them to suit personal tastes. It is axiomatic that the only adobe buildings which remain intact are those with weatherproofed roofs.

The most well-intentioned, carefully planned, and systematically executed archeological excavation, however scientific, is likely to create difficult preservation problems. The principal cause of destruction is the result of archeological work which neither proceeds nor ends upon a single plane (fig. 4). This leaves the site partially filled at many different levels. Water collects in an area of two or three rooms and cuts its way to lower levels. Deeply excavated portions are subject to the pressure of damp fill. The loose, moisture absorbing fill in rooms transfers water to concealed walls and diminishes the strength of adobe mortar. In a site of any complexity, burrowing and tunneling are particularly destructive, even when backfilled, since the fills will not be as compact as the material which was removed.

Regardless of the condition in which standing walls are found, it must be remembered that the entire depth of the wall is seldom exposed, and that the exposed portions—which form a base over which the stabilization is being done—have been subject to nearly all the forces listed above, i.e., surface weathering, construction over loose fill or partial walls, breakdown or theft of wood members, erosion at the base, buckling from pressure, excavation, and backfill (fig. 5).

Frequently, cattle cause more damage to ruins in the Southwest than people. Until they were fenced and under the protection of the National Park Service, the well-preserved cliff dwellings in Walnut Canyon suffered greatly by trampling of cattle seeking shelter in the ruins. Herds of sheep and goats have created preservation problems at sites in Canyon de Chelly and Hubbell Trading Post. Ironically, large and imposing adobe wall sections of the corral at Fort Bowie were reduced to low mounds by open range livestock during a brief span of eight years—from the time of the Service's initial investigations to that of the enacting legislation which created the Historic Site. Erection of fences was given top priority immediately following acquisition.

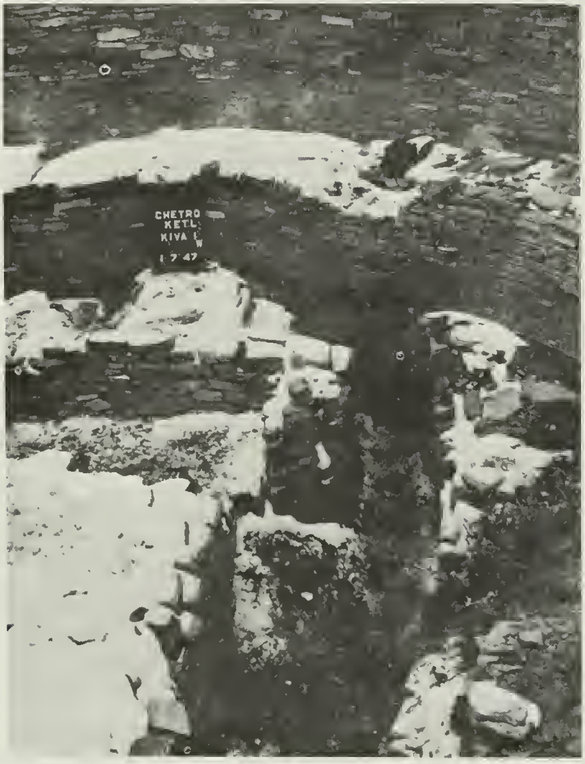


FIGURE 4. Excavation neither proceeds nor ends on a single plane and often leaves walls unsupported. (Kiva I, west perimeter, Chettro Kettle Ruin, Chaco Canyon National Monument, N. M.)

FIGURE 5. Clearing of depressed areas leaves them open to surface runoff and rapid destruction. (The Great Kiva, Kin Nahasbas Ruin, Chaco Canyon National Monument, N. M.)

3 Materials

PORTLAND CEMENT, CONCRETE AND MORTARS

Portland cement mortars are the most universally and effectively used materials for ruins stabilization in the western United States. The use of lime mortars is more prevalent in the East. Portland has a long history of use in stabilization. It was employed by Cosmos Mindeleff at Casa Grande as early as 1891, in mortar to set brickwork foundations and patches. It was used there again during the winters of 1906 through 1908 by J. W. Fewkes, in plaster coating to prevent erosion at the bases of walls. At about this time the first heavy concrete capping was placed on the Sun Temple in 1915.

Durability

Concrete has great resistance to weathering when properly made and placed in thick sections, or in thinner sections upon an unyielding material.

Compressive Strength

Up-to-date mixes of portland cement give compression strengths of 4 to 6 thousand pounds per square inch, and mortar strengths (concrete without the coarse aggregate) of 3 to 4 thousand pounds per square inch. These strengths are far in excess of any compressive strains that will be encountered in ruins stabilization.

Color

Concrete can be colored almost any desired tint, either by the addition of dry mortar colors or by stains. It is also possible to achieve a desired tint by selecting sand or an aggregate with certain color characteristics, or by using naturally colored cements.

Texture

While various textures, ranging from glassy smooth to rough, can be obtained with concrete, it is practically impossible to match a soil mortar texture because of the size of the sand grains.

Shrinkage

Concrete shrinks somewhat upon setting, and is increased appreciably by a high water-to-cement ratio, and by too rapid curing.

Tensile Strength

The tensile strength of concrete is very low. *It is a very brittle material*, an attribute that is generally not realized, or often ignored, Specifications for tensile strengths of mortars (portland cement and sand for use in setting stone) call for strengths of from 275 to 350 pounds per square inch. As Bauer states: "The question is frequently raised as to the value of a tension test when the concrete rarely ever is considered as having any tensile strength." Lack of such strength is the cause of most concrete failures, particularly the cracking of very thin capping.

Resistance to Moisture

Ordinary concrete or mortar is not particularly water-resistant. Even good concrete will absorb up to 20 percent of its weight in water. This absorption accounts for the fact that ordinary con-

crete used in the bases of walls, or as foundations, will not prevent the capillary rise of moisture into the wall above. In ordinary commercial work, waterproofing of concrete is accomplished in various ways:

1. With the use of a special waterproofing agent, usually tannin, added to the cement at the time of manufacture.

2. Addition, at the time of mixing, of hydrated lime or waterproofing compounds such as emulsified asphalts.

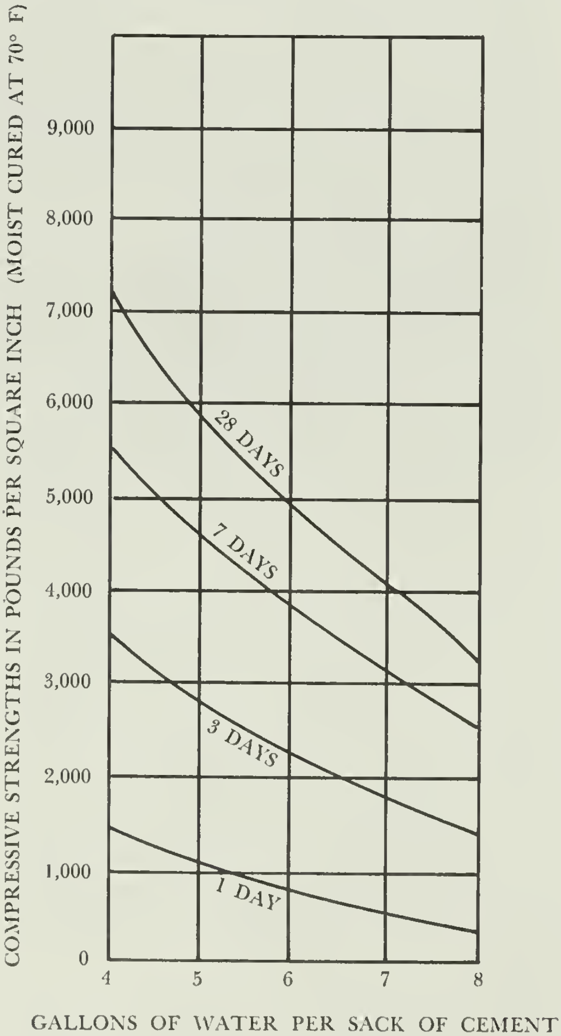


FIGURE 6. Strength curves for selected water-cement proportions. Data taken from Portland Cement Association publication entitled *Design and Control of Cement Mixtures.*

3. The use of mixes richer than those not intended to retain water, plus smaller amounts of mixing water. Restricting the mixing water will result in a much denser concrete; the longer concrete is moist-cured, the more dense and water-resistant it will be.

In most commercial work, however, concrete or mortar that must be waterproofed is treated after laying. Basement walls are protected by porous fill and drains, and then mopped with hot asphalt or painted with various materials intended to seal the exterior surface. The tops of masonry walls (stone, brick, tile, cinder blocks, etc.) laid in concrete mortars are either coated with asphalt or covered with asphalt-impregnated cloth, fiber glass, or paper, or with a combination of these materials. With these restrictions, then, the waterproofing of concrete and mortar for stabilization is practically confined to the addition of such compounds as emulsified asphalts at the time of mixing, or by the use of special waterproof cements.

Field Control of Concrete and Mortar

The design of concrete mixes and the drawing of specifications for cement and aggregates are functions of the branch of engineering of the particular agency engaged in the work, and that branch should be consulted for specifications. The Portland Cement Association, the American Concrete Institute, and the Building Research Institute also cooperate in disseminating building information. However, the data to follow on proportions and mixes are supplied for the field man who may not have technical assistance readily available for minor jobs.

The strength of concrete or cement mortar is affected by a number of factors. Among these are the ratio of aggregate-to-cement, ratio of water-to-cement, length of mixing, gradation of the aggregate, and length of moist-curing. Of all these factors, the ratio of water-to-cement is most important. Few supervisors and workmen seem to realize this. Strength curves for various water-cement proportions should be examined (fig. 6) as they show the rapid loss of strength as the ratio of water to cement increases.

In most specifications, the water-to-cement ratio is a controlling factor in design. Table 1, taken from a handbook, *The Design and Control of Concrete Mixtures*, issued by the Portland Cement Association, is intended as a reference for the construction of concrete piles, thin walls, light structural members, and exterior beams and columns.

Trial Mixes

Trial mixes may be made in the field to determine proportions of sand and cement for use with a given water-to-cement ratio chosen for required strength. A weighed or known quantity of aggregate is used, and when a suitable mix has been obtained, the unused material is weighed or measured and the quantity required for the mix is determined. To conduct a trial mix, a set of scales and a measure or box of 1/10th cubic foot capacity are needed.

For example, let us suppose that the concrete or mortar employed in stabilization will be laid in thin sections and will often be exposed to extreme weather, but will not be in constant contact with water. A ratio of 6 gallons of water to he sack is chosen. Following is an outline for the preparation of a trial mix:

Standard sized sacks of cement weigh 94 pounds and have a volume of 1 cubic foot. One gallon of water weighs 8.33 pounds. Fill the 1/10th-cubic-foot measure with cement. The cement should weigh 9.4 pounds.

Measure out, say 4 volumes of sand and weigh them. In this example, call the weight 32 pounds.

Six gallons of water to the sack would be 6 x 8.33 or 49.98 pounds of water for a whole sack. Water required for 1/10th sack is 4.998 or roughly 5 pounds.

Mix the 5 pounds of water with the 1 volume of cement (1/10th cubic foot or 9.4 pounds). The water-to-cement ratio for the mix is now established and no more water should be added.

To this mix add some of the 32 pounds of sand previously measured out. Continue to add sand until a workable mix is obtained.

At this point weigh and measure the sand that remains of the unused 4 volumes or 32 pounds.

If the sand remaining measures 1 1/4th volumes, the mix used at 6 gallons of water to the sack is, by volume, cement 1 part, sand 2 3/4ths parts.

If the weight of the remaining sand is, say 10 pounds, the mix is 1 part cement to 2 2/3rds parts sand by weight. With this ratio established, larger mixes may be made, always based on a portion of a sack of cement.

For 1/3rd of a sack of cement mix (a convenient size to use in the smaller mixers): cement, 1/3rd sack; water, 2 gallons; sand, 9/10ths cubic foot (at 1 part cement to 2 3/4ths parts sand by volume).

The field worker should be aware that an increasing number of gray portland cements have appeared on the market in recent years, ranging from Types I to III and from Types IA through IIIA. These have been created by demands of industry and technology. Type I is a general purpose cement suitable for most purposes. Type II cement is intended for use in mass concrete where control of hydration heat is necessary. It is recommended for use in structures of considerable size, where cement of moderate hydration heat tends to minimize rises in temperature. Such structures include dams, large piers, heavy abutments and retaining walls. Type III is a high, early strength cement designed for concrete which must be put into service rapidly, and is used in industrial and highway maintenance. Types IA-IIIA include a regular Type I portland cement into which an air entraining agent is integrally ground. This provides resistance to freezing and thawing, and prevents scaling action of de-icing salts and chemicals used in snow and ice removal. These cements are recommended for pavements, highways, etc. In addition to gray portland cements of six or eight types, several kinds of white cement have been developed. Finally, there is a waterproof gray cement known in the Southwest as plastic cement.

The important point to remember is that Type I portland gray cement should be used for most purposes under discussion here. Exceptions include masonry cements discussed below which, although forming a class of their own, are simply derivatives of portland.

Both Trinity white cement and a new, natural tan colored product (known by the trade name Warmtone, manufactured by the Trinity Portland Cement Company) have definite uses in stabilization, particularly in stuccos and plasters. It should be kept in mind, however, that in the restoration of a mortar with a high lime content, a lime mortar should be used. Differing coefficients of expansion and contraction between portland and lime mortars make the combination inadvisable for pointing or patching.

MASONRY CEMENTS

Masonry cement is a combination of portland and hydrated lime, usually in proportions of one-to-one, packaged in 1-cubic-foot bags weighing from 65 to 80 pounds.

Characteristics

The use of masonry cement is more widespread than straight portland cement mortars in commercial setting of brick, tile, masonry blocks, etc. The major reason for this is that mortars containing lime are much more workable than portland cement mortars. They are easier to handle and they trowel much better. Furthermore, masonry cement is cheaper. However, masonry cements are not as strong as portland cement mortars in tension or compression, although they should not be ruled out for pointing. Masonry cements are much less resistant to abrasion and should not be employed in capping or sections that may receive some visitor traffic. They may be colored with dry mortar colors in the same manner as portland cement.

Evaluation

The principal objection of masonry cements for use in capping is their lack of resistance to moisture penetration. Since manufacturers of waterproofing materials do not recommend their products for inclusion in lime-mortars, there seems to be no way to overcome this limitation. Therefore lime-mortar cements are not recommended for capping. However, recent experiments show that the water-repellent capacity of masonry cement can be improved by adding a waterproofed gray cement (Plastic, Medusa or equivalent). The ratio may be one part in five of the total mix, or equal parts of masonry cement and waterproofed gray cement, with three parts of sand (1-1-3). It should be mixed dry and the aggregate should contain just enough water for troweling. Because of their advantageous characteristics and slightly lower cost, these mortars should prove of value in the setting of large patches where very slight shrinkage and good bond with stone are needed.

Field Control

Mixes of lime-cement mortars are usually made by volume and not by a water-to-cement ratio. Most common mixes call for one part masonry cement, and two or three parts fine sand, with sufficient water to make a workable mortar.

SOIL-CEMENT MORTARS

Soil-cement is a mixture of portland with a suitable local soil brought to a workable consistency by the addition of water. The amount of cement varies from 5 to 20 percent by volume of the finished project. The primary reasons for using soil-cement in lieu of other mortars in stabilization work are 1) cost, 2) the extreme difficulty in obtaining concrete sand in some locations, 3) appearance in some special applications, and 4) suitability for use in monolithic soil structures.

A comparison of the qualities of soil-cement intended for ruins stabilization with the same material in its various commercial applications is difficult. Soil-cement used for roads, airport runways and hard standings, ditch linings, etc., is always laid fairly dry (at optimum moisture) and is heavily compacted. The compactive effort in such applications is equivalent to the force exerted by a 5 1/2 pound tamper dropped 75 times a distance of 12 inches upon 1/30th of a cubic foot of the material. Obviously, such requirements of moisture and compaction cannot be obtained when laying mortar. All material published on soil-cement is directed toward these commercial applications, and there is no known research on its use as a mortar.

History

The earliest use of soil-cement in stabilization appears to be its employment by J. F. Motz in 1934. He used it as a mortar between stone at Wupatki National Monument during a Civil Works Administration project. It was also used in the 1935 repairs at Tuzigoot in another WPA project supervised by Edward H. Spicer and Louis C. Caywood. While no records of this work are available, and it is not possible to determine precisely the type of mix used, the soil-cement samples at both areas show a rich mixture of cement (not less than 20 percent by volume) and an admixture of red mortar color. Some of this material is still in place at Tuzigoot after 37 years, attesting to its durability if properly made.

The first controlled tests of soil-cement made expressly for stabilization purposes were those conducted by A. E. Buchenberg between December 1941 and May 1946 (Buchenberg, 1951). These were carried on at Wupatki National Monument, and were simply outdoor exposure tests made on 6 x 10 x 3/4th-inch briquettes of the mortar. It should be noted that they were made by mortar samples only and did not include samples of masonry laid with this material, and that the briquettes were made in a semi-compacted state, a condition that is not possible to obtain when laying mortar.

Durability Tests

At the conclusion of the 4-year period of testing, Buchenberg found the material satisfactory. "A mixture of soil and cement stands up very well under exposure to climatic conditions, with an approximate admixture of from 15% to 20% cement...." (Buchenberg, 1946) A series of tests was carried on later at Chaco Canyon to determine the durability of soil-cement mixtures under conditions of wetting and drying, and freezing and thawing, and the strength of the bond between mortar and stone under the same conditions.

Only two general types of soils in the tests were available for use in stabilization in the area. One variety, classed as Soil A in the notes, is a heavy, dark-colored and poorly drained clay, 64 percent combined silt and clay. It appears to fall into USBPR Classes A-6 and A-7. The other, classed as Soil B, is a silt-loam, rather fine, poorly graded, 18 percent combined silt and clay, probably USBPR Class A-5. Both soils may be considered as fine-grained under the Unified Soil Classification System. (See: *Earth Manual: a Guide to the Use of Soils as Foundations and as Construction Materials for Hydraulic Structures*, U.S. Department of the Interior, Bureau of Outdoor Recreation, 1963, Washington D.C.) Soils containing more than 50 percent visible particles are classed as coarse-grained, while those containing less are fine-grained. For classification purposes, the No. 200 sieve (0.074 mm., or .003-inch) will separate the fine- and coarse-grained types. Particles of .003-inch size are about the smallest that can be seen by the unaided eye.

Mixes of varying cement content were made above optimum moisture in these tests, and at a consistency which could be troweled. The wet-dry tests were run on molded cylinders of soil-cement approximately 1/30th cubic foot in volume. Test cylinders were moist cured for seven days after molding. Each soil-cement cylinder was placed under water at room temperature for five hours. They were then dried for 42 hours, which completed one cycle. Although 12 cycles are considered a complete test, the cylinders in question were run through 22 cycles. Standard wet-dry tests for soil-cement specified by the American Society for Testing Materials (ASTM Designation D-559-44) require that each cylinder be wire brushed at the end of each cycle, the cylinder weighed, and the soil-cement loss computed. Lack of suitable balances prevented the completion of this part of the test.

The same kind of cylinders, cured the same length of time, were used in the freeze-thaw test (fig. 7). After curing, the soil-cement cylinders were placed on absorptive pads which extended into a pan of water. Thus, the soil-cement had a constant supply of moisture and there was no limit to the amount available for absorption. Soil-cement and portland will absorb large quantities of moisture (up to 20 percent) and it is useless to try a freeze-thaw test without making moisture available.

Standard procedures (ASTM Designation D-560-44) require that the cylinders be frozen for 22 hours at -10° F. This requirement could not be followed in the field. No freezing cabinet was available, so the cylinders were frozen outdoors at temperatures ranging downward to -24° F. After freezing, the cylinders were thawed for the required 22 hours, the completion of one cycle.

No tests were known to determine the strength of bond between rock and mortar, so the following procedure was carried out in the field: After the wet-dry and freeze-thaw cylinders were made, two average sized rocks were dampened, the mortar spread roughly on one, and the second rock tapped lightly into place upon the first. Thickness of the mortar between the rocks averaged 3/8ths inch. These were cured for seven days. The mortar specimens were tested for resistance to wetting and drying for six cycles along with and in the same manner as the cylinders. It was found that this soil-cement was far more resistant to wetting and drying than to freezing and thawing. At this point, the wet-dry test on mortar was stopped and the rock samples with mortar between were transferred to the freeze-thaw test. Thus, all the mortar samples passed six cycles of wetting and drying before undergoing the freeze-thaw test. A summary of the results of 10 exemplary tests is presented in table 2 and in the following observations:

1. Mixes of straight Soil A (adobe) were very hard to work and tended to crack. They were disregarded and do not appear in the tabulation of results.

2. As little as 10 percent cement by volume gave satisfactory resistance to wetting-drying cycles. All cylinder samples at or above 10 percent cement passed 22 cycles without failure, and six cycles without destroying the bond between rock and mortar.

3. Cement in the amount of at least 14 percent for cylinder samples was required to resist the action of repeated freezing and thawing. Cylinders at cement content less than 14 percent disintegrated at the third cycle. Observation of the cylinders undergoing tests indicates that no amount of cement will prevent the soil-cement from absorbing moisture either under freeze-thaw or wet-dry conditions. Cement strength must be high enough to resist the force of freezing after the moisture has entered the specimen. Moisture rise in a cylinder 4 inches high was 2 to 3 inches. When cylinders failed under freezing, there was no gradual wearing away of the exterior, but rather a breaking up of the entire area that had absorbed moisture.

4. Freeze-thaw tests on bond were far more severe than either freeze-thaw or wet-dry tests on cylinders. Thus, samples which pass a freeze-thaw test may not retain a strong bond with stone

FIGURE 7. Selected cylinders subjected to freeze-thaw test. Nos. 14 and 16, with 10 and 12 percent cement by volume respectively, failed at the third cycle. Both were made up with equal parts clay and silt-loam. No. 20, with 15 percent cement by volume, is shown at the 12th cycle. Nos. 7 and 8, consisting of three parts clay, two parts silt-loam, and emulsified bitumen, were tested in conjunction with the soil-cement and are shown at the 15th cycle.

when subjected to weathering. This failure is probably attributable to the fact that some of the moisture entering the soil-cement is absorbed by clay particles which causes the entire mass to expand and break the bond.

TABLE 1. Optimum water-to-cement ratios for various climates and conditions.

Exposure		Ratio
Extreme.	Severe northern climate alternate freezing and thawing, wetting and drying.	5 1/2 gallons of water per sack
Severe.	Northern climate, rain and snow, freezing and thawing, but not in contact with water.	6 gallons of water per sack
Moderate.	Ordinary southern U.S. weather, but not continuously in contact with water unless completely submerged and protected from freezing.	6 3/4 gallons of water per sack
Protected.	Enclosed structural members, concrete below ground, not subject to freezing.	7 1/2 gallons of water per sack

Note should be taken of samples 54, 55, and 56 (table 2). Soil B, which contains only 18 percent combined silt and clay was mixed with equal proportions of concrete sand. These samples exhibited the greatest resistance to the freeze-thaw test on mortar bond. They still absorbed moisture, but it caused no appreciable weakening of the bond. The clay content was reduced to 9 percent which evidently is low enough to prevent much change in the volume of the mass upon repeated freezing and thawing.

5. Mixes containing large amounts of clay were less stable than those with less clay and more sand. Twenty percent cement with clay produced no more strength than 14 percent with a lower clay content.

6. In all cases where bond failed, the edges of the mortar remained hard and sharp. Failure of the bond does not necessarily mean that the soil-cement has disintegrated.

7. The addition of a bitumen to samples 23 through 31 demonstrates that the additives do not increase the moisture resistance of soil-cements, but merely compound the problem of tinting.

Compressive and Tensile Strength

Soil-cement is usually tested by its reaction to the wet-dry and freeze-thaw tests, and seldom by compression. No tests for tension have been found. Recorded compression tests indicate 28-day strengths of from 200 to 1,078 pounds per square inch. This is considerably less compressive strength than is developed by concrete mortar, but under all normal circumstances it is sufficient.

Color

A. E. Buchenberg made a suitable mix without the addition of mortar color at Wupatki National Monument by carefully selected, dark red soils. However, in most areas the addition of standard mortar or cement colors will be required to obtain proper tint.

Texture

The texture of soil-cement is good. It more nearly matches the texture of prehistoric mortar than does either cement or lime-cement mortars.

Moisture Resistance

Soil-cement is no more moisture resistant than concrete or cement mortars. In the cylinders tested, there was a moisture rise of from 2 to 3 inches in cylinders 4 inches high. The strength of the cement in the mix prevents disintegration with such high moisture absorption.

Evaluation

Soil-cement is not recommended as a mortar for setting stone unless its use is unavoidable in remote areas or necessary to simulate original material. In these instances the cement content must be unusually high, 15 to 20 percent, to insure the best possible bond. The more sandy soils should be selected. Because of its good texture, soil-cement is particularly adapted to appli-

TABLE 2. Results of 10 exemplary soil-cement tests.

Cylinder Number	Soil Type	Percent Cement by Volume	Freeze-thaw Results	Wet-dry Results	Bond Results (Freeze-thaw)	Remarks
14 15	A-1 B-1	10 10	failed 3rd cycle	passed 22 cycles		
16 17	A-1 B-1		failed 3rd cycle	passed 22 cycles		
20 21 22	A-1 B-1	15 15 15	passed 12 cycles	passed 22 cycles	failed 3rd cycle	cyclinders absorb moisture quite rapidly
23 24 25	A-1 B-1+	12+ bitu- men	passed 12 cycles	passed 22 cycles	failed 6th cycle	rather heavy salt (?) deposit on cylinders
26 27 28	A-2 B-3	14+ bitu- men	passed 12 cycles	passed 22 cycles	failed 6th cycle	in spite of failure of bond the mortar re-mains hard. Salt (?) deposit
29 30 31	A-1 B-2	14+ bitu- men	passed 12 cycles	passed 22 cycles	failed 6th cycle	absorbs moisture rapidly
32 33 34	A-1 B-3	14 14 14	passed 12 cycles	passed 22 cycles	failed 6th cycle	
35 36 37	A-1 B-3	20 20 20	passed 12 cycles	passed 22 cycles	failed 6th cycle	mortar hard
45 46 47	B-100%	16 16 16	passed 12 cycles	passed 22 cycles	failed 6th cycle	
54 55 56	B-1 sand 1 (con- crete sand)	16 16 16	passed 12 cycles	passed 22 cycles	passed 12 cycles	

cations where large amounts of mortar must be left exposed; these include heavy grouting of exposed longitudinal sections where facing is not replaced (figs. 8 and 9).

Soil-cement is particularly suited to large repair sections in monolithic soil structures, and is also valuable in stabilizing the sides or ends of cuts in excavations which must be left open for interpretive purposes (fig. 10).

Procedures for making optimum moisture and density tests for determination of cement requirements are not reproduced here inasmuch as they require equipment and data not generally available in field areas. Detailed instructions may be found in two publications of the Portland Cement Association: *Soil Cement Mixtures; Laboratory Handbook*, and *Testing and Construction Criteria for Soil-Cement for Highway Ditch Linings, Levee Faces and Similar Structures;* and *Manual on Sampling and Testing for Construction Control, Airport Pavings, Roads and Streets*, available from the U.S. Corps of Engineers.

FIGURE 8. The use of heavy grouting to replace native soil between random stone; after 10 years exposure to the elements. (West Ruin, Aztec Ruins National Monument, N. M.)

Field Control of Soil-Cement

In general practice, the cement content for soil-cement must be based on the percent of cement by volume to the volume of the completed product. It is also standard practice to make trial cylinders of the mix at varying cement content, and with several available soils, subject these test cylinders to standard ASTM wet-dry and freeze-thaw tests before establishing a mix for any particular job. The following information on cement requirements is suggested as a basis for conducting field tests of soil-cement mixtures: (Tests should be made well in advance of actual work.)

Sandy soil, well graded: 8, 10, and 12 percent cement will harden 79 percent of these soils. A few will require cement volumes of 19 percent or more.

Coarse, little binder: 12 and 14 percent cement will harden 73 percent of these soils. A few may require up to 18 percent cement.

Silt soil: 12, 14, and 16 percent cement will harden 69 percent of these soils, while 28 percent will require 18 percent or over.

Clay soils: 14, 16, and 18 percent cement is required to harden most of these soils, while a few will need cement content as high as 21 percent.

A definite trend is observable for the cement requirements to increase as the silt and clay content of the soil rises. Heavier clay soils not only require higher cement content, but are much harder to handle and place than are the lighter and more sandy types; these heavy soils should be avoided if at all possible.

A simple test to determine classification and gradation of soil may be made as follows:

1. Fill a straight-sided jar about one-third full of earth which has been screened by a No. 4 sieve (about 1/4th inch).
2. Add water to fill jar about two-thirds full.
3. Cover jar and shake vigorously until all of the earth is in suspension.
4. Allow earth to settle until the various particle-size divisions are visible (about 30 minutes).

The coarser material, No. 4 (about 1/4th inch) to No. 10 (about 3/32nd inch) will settle to the

bottom (figs. 11, 12). The medium-sized material, No. 10 (about 3/32nd inch) to No. 40 (about 1/64th inch) will then settle. The fine material and colloids, No. 40 (about 1/64th inch) to No. 200 (about 3/1000th inch) and smaller, will rise to the top.

A good distribution of all particle sizes from large to small indicates a well graded soil. The soil is poorly graded if all particles are uniform in size, or if there is an absence of intermediate sizes. If the visible particles (up to 200 sieve) make up more than 50 percent of the sample, the soil is coarse-grained. Soils containing less than 50 percent visible particles are fine-grained. If the sample being tested is a fine-grained soil, coarse sand (No. 4 to No. 10) must be added to make up 50 percent of the visible particles to provide a suitable soil for making soil-cement. Soil samples should then be tested with varying percentages of cement to determine optimum mix. If tinting is required to match proposed work, cement color should be admixed during these tests.

Treatment Curing

Soil-cement may be mixed by hand for small jobs or in a standard plaster mixer with rotating blades. It is difficult to handle in a drum type mixer, and cannot be worked to advantage unless in a plastic condition. It should be resilient from the beginning to keep the workmen from adding uncontrolled amounts of water. It need not be so thin as to be "buttered on" when used as a mortar, but should be plastic enough so that when the stone is set and tapped in place, the mortar will flow to meet the inequalities on the surface of the stone. The weakest part of such construction is the bond. The stone should be well dampened to aid the mortar in adhering, and to prevent the stone from absorbing excess moisture from the mortar. It takes at least seven days of damp curing for soil-cement to set—the same as other cement mixes. The same precautions should be taken in curing soil-cement as are taken with portland or masonry cements. Keep it damp under wet earth, sacks, or other covering.

FIGURE 9. Soil-cement in heavy cross section; shown here for the repair of slab-house walls. (Basket Maker III pithouse, Site Bc-51, Chaco Canyon National Monument, N. M.)

FIGURE 10. Formed soil-cement in retaining sections of fill which must be stabilized to show portions of structures on varying levels. (Great Kiva in the plaza of Chettro Kettle Ruin, Chaco Canyon National Monument, N. M.)

SOIL-BITUMEN MORTARS

Soil-bitumen, or asphalt stabilized soil, is a mixture of emulsified asphalt and soil with sufficient mixing water for the purpose intended. Upon evaporation of the mixing water, the soil particles are left covered with a thin film of bitumen. There is no chemical action involved, nor does the bitumen act as a binder, glue, or other cementing agent. In all soil-bitumen mixes, the strength of the resulting product depends solely upon the cohesive action or quality of the clay particles in the soil.

In the commercial field, the use of soil-bitumen has been limited to the manufacture of bricks for building construction. One point that is brought out in specifications for buildings of this type is that manufacturers of emulsified bitumens do not recommend the use of their product on mortar for setting stabilized bricks or adobes. They recommend only the use of a sand-concrete mortar without the addition of lime. On the other hand, experiments conducted by the U.S. Office of Indian Affairs with stabilized adobes indicate that a soil-bitumen mortar, used in the same proportions as that for adobes, may be successfully employed (Hubbel, 1943, p. 91).

The first extensive use of soil-bitumen in ruins stabilization was made by the C.C.C. Mobile Unit at Chaco Canyon National Monument in 1937. Its use was dictated by funds quite limited in proportion to the number of man-days available for labor. Since the termination of that program, the use of soil-bitumen has been limited to small areas of plating, walkways and similar applications.

Durability

Properly made and laid soil-bitumen projects are durable as demonstrated by jobs at Pueblo Bonito, Wijiji, Kin Klizhin and Aztec Ruins, completed from 1937 to 1940. With a few excep-

FIGURE 11. Distribution of soil and vegetal material after step 4 of soil gradation.

tions which can be traced to poor technique, this work is standing up well. Its useful life without repairs is estimated at 25 to 30 years. Where unsatisfactory results have occurred, often in applications not connected with stabilization such as plaster, roof platings, thin walks, etc., failure can be attributed to three primary causes: A durable soil-bitumen mix cannot be made where the soil contains more than 2 percent of soluble salts. Lack of proper tests for salts resulted in several failures. Improper amounts of bitumen, in an excess over that necessary to waterproof the clay particles in the soil, results in excessive shrinkage and a total lack of bond. Improper applications result in failure, as in thin plating and roof coverings where it was mistakenly presumed that the bitumen would provide more strength than that inherent in the soil.

Failures of soil-bitumen in ruins stabilization are seen in these instances: 1) where it was used in very thin "membrane capping" (failures were the result of cracking and lack of bond, not loss of waterproofing); 2) very thin vertical patches at the sides of doorways where there was lack of sufficient bond with the remaining wall (some failures were also due to excessive use of bitumen in the mix); and 3) vertical sections and patches at corners in doorways, etc., which were subject to heavy visitor traffic.

The most satisfactory employment of soil-bitumen is seen in: 1) heavy capping where three to five courses of masonry were relaid in the mortar (most effective in thick core-type walls where there is an excess of mortar over stone); 2) in areas of large patches; and 3) in repairs made to correct basal erosion in damp areas. Soil-bitumen mortars are far more moisture resistant than other types.

Evaluation

Present day uses of soil-bitumen are rather limited and no extensive data are presented here. Details on testing, strengths, water permeability, selection of soils, etc., can be found in several publications, including *Specifications, Bitadobe Brick and Building Conforming to Minimum Requirements Approved by Pacific Coast Building Officials Conference* (supplied by American Bitumuls Co., 200 Bush Street, San Francisco, Calif.); *Technical Paper No. 53, Hydropel Emulsified Asphalt*, issued by the American Bitumuls Company; *Bulletin BMS 78, Structural, Heat Transfer and Water Permeability Properties of Five Earth Wall Constructions*, National Bureau of Standards, Washington, D.C.; and in an unpublished manuscript, "Interim Report on Experimental Ruin Stabilization at Wupatki National Monument" (Buchenberg, Ms., 1946) on file, Arizona Archeological Center, National Park Service, Tucson, Ariz.)

The first requisite of soil or soil-bitumen mortars is that it contain not more than 2 percent soluble salts. If there is doubt, the soil should be tested by a competent laboratory because the deleterious effects of the salts will not become apparent until some time after the mortar has been laid. If it is satisfactory in this respect, the next requirement is that it contain from 30 to 45 percent clay, or combined silt and clay, which will pass a 200-mesh screen. Should the only soils obtainable contain too large a percentage of clay, they may be tempered by the addition of sand.

Trial bricks can be made using 4 to 8 percent bitumen by weight to roughly determine the best proportions of bitumen to be added. After a drying period of two weeks, the bricks can be examined for shrinkage and cracking. Those that are satisfactory in this respect can be further tested by soaking in water, or subjected to a stream of water to determine their resistance to

FIGURE 12. A close-up view of a well graded soil after suspension in water and settling.

erosion. In general, the most satisfactory mixes will be those which are water-resistant but do not contain an excess of bitumen.

During hot, dry weather, soil-bitumen capping and plating will require some protection to prevent too rapid drying and resultant cracking. Probably the best and easiest covering to apply is damp soil, preferably a light sandy loam that dampens easily. It can be applied after the surface has become firm and it need not be removed.

CONCRETE ADMIXTURES

Emulsified asphalts are added to concrete and cement mortars at the time of mixing to reduce moisture absorption. They are intended for use in foundations and mortars; manufacturers claim a reduction in moisture absorption of from 75 to 85 percent. Claims are also made for increased workability and consequent reduction in the water-cement ratio.

Asphalt Types

Experiments have been made with a heavy asphalt called "Floor Mastic Binder" intended for use in floors and foundations. It was incorporated in concrete used as a foundation for damp kiva walls. Two drawbacks were encountered: First, it was extremely hard to handle; it gave the concrete a molasses-like consistency that could not be poured, shoveled or troweled. Secondly, it was coal-black, which required that it be well disguised with soil pointing. It would appear to be unsatisfactory as a mortar.

The emulsified asphalt known by the trade name of Hydropel and intended specifically for use in mortars was satisfactorily employed in damp walls in Chettro Kettle during 1947. It was also used successfully at the large West Ruin, Aztec, for the construction of curtain walls along the foundations of rooms where capillary moisture and erosion of basal stones were creating severe problems and threatened the collapse of upper wall sections. Its color is somewhat dark, and it appears to be unaffected by mortar colors

incorporated in the mix. This is a minor inconvenience and, if necessary, can be overcome by pointing with soil or other native mortars.

Mortar Colors

Concrete mortars should be tinted with dry earth colors to properly blend with the remainder of the structure. Correct shades of mortar or cement colors are often difficult to obtain from local sources. Color charts may be obtained from manufacturers and the materials ordered well in advance of the intended starting date. Note should be made that the colors are certified lime proof, non-fading, and that 85 percent will pass a 200-mesh screen.

Samples should be made up in advance of actual work to test the reaction of the color to the particular cement in use; some brands of cement are harder to color than others. Color and texture of the sand aggregate affect the final product very noticeably. If possible, sand that matches the ruin should be selected. The color of the dry mix is a fair guide to the appearance of the completed mix, but in any event do not use more than 10 percent color since it may affect the strength of the concrete.

Add the color to the dry cement first. It is most convenient to mix a quantity of the cement and color in a large can or half barrel. It does not matter too much if all the various batches are not exactly the same shade; in fact, it may be necessary, where much mortar is exposed, to change tints often to duplicate changes in the original material.

BONDING AGENTS

The problem of bonding new mortar or concrete to old surfaces so that it will remain permanently in place has been the subject of considerable research and development, particularly in the decade 1958-1968. Only two companies and their products will be mentioned, since excellent results have been obtained with their products under field conditions. However, this discussion is not intended to denigrate other firms which may be manufacturing similar products of equal merit.

In the commercial field, it was found that a straight portland cement grout would provide an adequate bond between the new and old concrete, but only if the new section were thick and heavy, if edges were square cut, and if the entire patch area were roughened and cleaned. This requires considerable time and effort. The grout, too, must be mixed and applied very carefully. Too much moisture in the grout causes shrinkage and subsequent cracking; too little results in bond failure. The topping has to be applied when the grout hardens to the proper point of setting. This laborious, complicated, and time consuming method was necessary to secure an integral bond between new and old concrete. Even with these precautions, failures were all too common. Under many conditions, it became evident that portland cement grout by itself could not provide an adequate bond.

In an attempt to solve this problem, the first bonding agents were developed, i.e., rubber latex, polyvinyl acetate emulsions, and compounds with an asphalt base. But natural rubber latexes are affected by alkalies present in cement, and therefore tend to break down. They also oxidize in the presence of air. The use of bituminous materials resulted in a resilient surface but had scarcely any advantage as bonding agents.

Chemists approached the problem from the most promising of these directions. It was well known that polyvinyl acetates have excellent adhesive properties and, in emulsion form, are compatible with all mortars and concretes. They are relatively inexpensive. Unfortunately, these materials are also normally water soluble. They tend to re-emulsify and weaken when continuously exposed to moisture, as in outdoor applications or on cellar walls. Chemists then discovered a method whereby high polymer resins can be internally plasticized to withstand exposure to moisture and vapors without re-emulsifying, yet retain their superior adhesive qualities. Daraweld is such a commercial product. When properly used, it will not soften or disintegrate because of moisture, and can be used in damp areas, both indoors and outdoors. It will also

stop most leaks in below-grade masonry. The coupling action of colloidal resin particles is so strong in Daraweld grouts and mortars that they will bond not only to concrete and masonry, but to tile, wood, steel and glass. Containers and tools used in handling Daraweld must be cleaned with water immediately after use. Mixed in proportions ranging from 1:1 to 1:4 with water, in the usual grouting or pointing mortar, it has been used very effectively in numerous ruins repair jobs. Also, where thin patches, overlays or tinted plasters are employed, it can be mixed with water and soil to form a very durable soil mortar.

Daraweld mixed 1:1 with water, sprayed or brushed on an adobe or soil mortar surface such as the eroding front portions of Montezuma Castle and followed by patching or plastering with soil mortar which matches the original, will provide an excellent bond for the new work. In 1960 this same mixture was applied as a spray to the floor of an early pithouse site, an interpretive archeological exhibit, near Montezuma Well. This treatment has been a major factor in prolonging the preservation of a fragile exhibit.

Daraweld is manufactured by the Dewey and Almy Chemical Division of the W. R. Grace and Company, with offices in Cambridge, Mass.; Chicago, Ill.; San Leandro, Calif.; and Montreal, Canada. It is sold in 1-, 5-, 29-, and 54-gallon drums, available through prominent construction supply firms in most of the larger cities.

The Dow Chemical Company of Midland, Mich., manufactures a Dow Latex 560, which, added to cement mortar, provides increased adhesive or bonding strength, better compressive, tensile, and flexural strength, and improved alkali and dilute acid resistance. This material provided an excellent bond and the necessary strength for a stone masonry retaining wall anchored to bedrock on a 60 percent slope in Mummy Cave, Canyon de Chelly.

WOOD PRESERVATIVES

Most modern treatments for the preservation of wood are based upon poisons such as pentachlorphenol which prevents the growth of fungi. They may be used in stabilization for preservation of replaced timbers, or for the treatment of wood members already in place. Some of the newer preservatives, sold in gallon lots or more, contain both pentachlorphenol and silicone, thus providing combined protection against fungi and moisture. Some preparations are sold in concentrated form and are designed to be mixed with petroleum oils. Kerosene and very light fuel oils or napthas have been found satisfactory. It is suggested that prior to actual use, tests be made with the wood involved. Some preparations will produce "blooming," the appearance of iridescent colors on the surface. Since this is apparently due to the petroleum dilutent, various types can be tried and those with the best appearance employed. A word of caution: when mixing and handling these preparations, extreme care must be taken to protect the eyes and face. Limited contact with the hands is not serious, but prolonged contact must be avoided.

Application

New material or beams which have been removed and are to be replaced can best be treated by soaking. Timbers in place are harder to handle. Exposed parts can be painted in several applications, but the portions of any timbers which need treatment most are those embedded in walls or other parts of the structure. The most satisfactory solution though not perfect is to drill a 1/2 or 3/4ths-inch hole on an angle into the embedded end and keep this full of solution until it has soaked through to the surface, plugging the hole after the treatment.

NON-TOXIC INSECTICIDE

Silica aerogel, an excellent non-toxic powder, has been used effectively in recent years to treat ceiling and roof timbers *in situ* which were heavily infested with powder post beetles and other insects. A special rubber syringe with adaptable nozzles, filled with powder, is used to dust the borings and larvae runs. The powder causes death by suffocation.

SILICONE WATER REPELLENTS

The long history of waterproofing agents applied to prehistoric structures, particularly those

of soil construction at Casa Grande National Monument, is reviewed elsewhere in this volume. The history was one of failure. Failure in almost every instance was due to the fact that the waterproofing compounds always formed an impervious skin or surface. Moisture absorption from the soil below the wall, differential expansion of the pervious surface and the wall interior, and other factors forced a separation of the treated surface from the remainder of the wall. The damage caused by loss of the treated surface was often greater than that from natural weathering. While these waterproofings were suitable for such hard surfaces as brick or limestone, they were not applicable in the treatment of soil walls. Additional difficulty was encountered where treatments discolored the aboriginal surface or gave it a sheen or gloss.

Silicone waterproofings developed for above-grade masonry in the 1960's (late spinoffs from American technical developments in World War II) provide a water repellent surface and avoid many of the difficulties encountered with the older type. Their effectiveness is based on their peculiar surface structure. They do not form an impervious skin. Rather, when applied to masonry and other semiporous material, their surface becomes a network of small open cells or pores which repel water. It also permits moisture, entrapped within the wall, to evaporate through this honeycomb surface. As a result, there has been no separation of treated surface from the remainder of the wall in structures which were treated as long as 10 years ago. Furthermore, the silicone preparations do not form a glossy or noticeable surface. The treated surface will appear somewhat darker for some time after application, but disappears within a few weeks.

Limitations

Silicone water repellents do not harden surfaces to which they are applied. If the surface is friable before treatment, it will remain so following treatment. Should the repellents be applied to areas that are brushed by heavy visitor traffic or otherwise abraded, regular inspection must be made to insure that the treatment is not lost. Inspections made during a rain will instantly disclose areas on which the repellent is no longer effective.

Silicone Types and Content

The basic silicones for water repellents are made by a few large manufacturers. They are then processed by other manufacturers into a bewildering array of masonry and other water repellents. Of the types which have been tested for use on monolithic soil or masonry structures, only those which have a hydrocarbon base or vehicle are approved. Other types, with a water base and caustic action, may prove satisfactory but have not as yet undergone sufficient testing to be recommended.

When testing of silicone products began, a number of producers were contacted regarding the guaranteed silicone content of their products. One manufacturer assured a silicone content of not less than 5 percent and not more than 8 percent. This was the highest percentage guaranteed, although one manufacturer offered to produce a water repellent at any desired silicone content. As a result of these inquiries, all testing and application of silicone water repellents in the Southwest has been made with material having a silicone content of not less than 5 percent. It should be made clear, however, that a 5 percent content will be too high for very low porosity substances such as granite, and that the silicone content should be adjusted to the porosity of the material on which it is used.

Application

To date, applications of silicone water repellents have been made on the following structures: south wall of the "Big House" at Casa Grande and numerous walls in Compound A (figs. 13, 14) which had been previously covered with a soil-cement coating, and heavy soil-cement sections in Compound B. At Tumacacori the entire granary was treated and an application was made on the patched upper surface of the barrel-vault roof on the sacristy.

The applications on the above structures were made because of the extreme porosity of their surfaces and their susceptibility to weathering. Silicone water repellents should greatly extend

the life of cement mortar capping and similar repairs. However, on typical porous Southwestern structures it is recommended that no application be made at a rate greater than 1 gallon to 50 square feet. Application is best made by a low pressure spray adjusted so that a very coarse stream is produced. Do not use a fine spray. Application should be heavy enough so that there is a rundown of from 6 to 8 inches below the strip being sprayed. The hydrocarbon vehicle is toxic if breathed in a confined space, and it is important that workmen wear an approved type painter's mask or respirator.

FIGURE 13. West wall of Compound A immediately after a rain. The light areas treated with silicone repelled water. The darker areas were untreated and absorbed moisture rapidly. (Casa Grande Ruins National Monument, Ariz.)

PLASTIC AND RESIN COMPOUNDS

The use of plastics in ruins stabilization is in the experimental stage. They appear to have some uses in the special applications noted below.

There is an almost unlimited number of plastic compounds of the polyethylene and polystyrene types. They are specifically compounded for a variety of uses. Some, which are produced in pellet or granular form, can be dissolved in various solvents, the type depending upon the characteristics of the plastics. Some plastic coatings can be dissolved in water. The thought behind recent experiments is that plastics may find a use in hardening floors of such exhibits as pit houses, floors with special features, and possibly the soil walls of pit houses and similar substructures.

One type of polystyrene in pellet form will dissolve in benzene. Penetration of this solution into soil is excellent. The result is an impregnated soil which is waterproof and resistant to most acids or other substances which would be encountered on a substructure. However, it is not durable enough to be walked upon. This may be the result of improper technique in application, since polystyrene is a thermosetting plastic and may require additional heat in order to reach its maximum strength. On the other hand, compounds of greater impact strength, now being tested, may provide sufficiently durable without the addition of heat. Some emulsified types of polyethylene in liquid form, used for strengthening a variety of products from asbestos shingles to paperboards, also may be suitable for these applications.

Epoxy resins such as Bakelite's resin No. E R L 2795 are receiving increasing commercial use for applications ranging from cementing precast curbs and gutters on concrete roadways to the cementing of loose section of coal mine roofs (*The Coal Age*, vol. 63, Jan. 1957).

FIGURE 14. West wall of Compound A one year after the application of silicone waterproofing. Two hairline cracks were filled. The untreated smears of plaster have absorbed moisture, while the treated wall remains dry. (Casa Grande Ruins National Monument, Ariz.)

The most promising new product on the market is a concrescent epoxy adhesive of the Adhesive Engineering Company, San Carlos, Calif., a firm which has perfected a structural concrete bonding process. Introduced within the past 10 years, this process may have application in structural repair of ruins, particularly those with cracked masonry walls.

By this method, all crack surfaces are temporarily sealed except for occasional open ports. A gun is placed against one of the ports and an extremely strong, fast-setting epoxy injected into the crack at pressures of up to 300 p.s.i. When all ports have been filled, the temporary surface seal is removed. The epoxy is forced under pressure throughout the entire crack system, totally filling lateral and hairline cracks. Crack depth is no limitation.

The equipment used is compactly contained on a small, easily maneuvered two-wheeled hand truck. It consists of two containers holding the components of the fast curing, two-part epoxy adhesive (the resin and the curing agents) used for injection, and power driven pumping equipment that provides pressure for the operation. Two flexible hoses extend from the truck to the hand-held injection gun. The two-part epoxy is fed through these and mixed in a special in-line mixing chamber at the gun.

Several conditions must be met if this technique is to be successful in ruins stabilization: 1) as is the case for whatever method is used to repair cracks in walls, the cause of the cracks must be eliminated; 2) optimum pressure for injection of the epoxy is to be determined, preventing any possible hydraulic pressure which might damage the remainder of the wall; and 3) provisions must be made for injecting epoxy at depths beneath the face of the wall, leaving sufficient space to perform surface repairs which will match surrounding masonry and thus obscure the epoxy-filled cracks.

While it is doubtful that the day is fast approaching when an entire site can be indefinitely preserved in either plastics or resins, some of the new materials now under test may provide solutions to specific preservation problems.

HYDROZO CLEAR COATING

A preservative spray which has enjoyed considerable success in the Eastern United States, particularly on stone and brick masonry, is Hydrozo Clear Coating. It was first produced in the early 1900's by E. E. Blackman, State Archeologist for the Nebraska State Historical Society in Lincoln, Nebr. According to the manufacturer's literature, Blackman "discovered and unearthed ancient pottery shards in a very wet soil that normally would have caused their disintegration, and further study at the Museum showed a resinous substance was responsible for their unique preservation. Several years of research and experimentation were necessary before this resin was reproduced by Mr. Blackman as Hydozite; and he then perfected a liquid formula, Hydrozo Clear Coating, for masonry and other porous surfaces." Since that time, the Hydrozo Products Company has produced other water repellent coatings for above and below grade stone and brick masonry, as well as for wood and concrete.

Only the Hydrozo Clear Coating will be considered here. The National Park Service has used this coating to preserve the restoration of some historical buildings, including Congress Hall in Philadelphia; the Mission of San Carlos, St. Augustine, Fla.; and the Old Meeting House in Alexandria, Va. Resembling paint oil or turpentine, Hydrozo Clear Coating consists of waterproof synthetic gum in formula with a volatile hydrocarbon thinner. It penetrates pores by capillary action, sealing the surface.

	Percent by weight	Percent by volume
Analysis:		
Synthetic Gum Resin Solids	21	19
Aliphatic Thinner	79	81
	100	100

Specifications: Areas to be treated should be given two coats of Hydrozo. All surfaces must be dry and the temperature should be 55° F. or higher. If there is water or heavy dampness apparent on the surface, it will repel the coating. At temperatures lower than 55° F., Hydrozo may

congeal on the surface. Surfaces must be clean, free from cracks, and all repointing which is needed should be done before application. If alkali is apparent, it should be removed with a brick cleaning compound or a solution of 15 percent muriatic acid. An acid, of course, should *never* be used on such substances as lime mortars, limestone, or marble. Hydrozo Clear should be applied with a wetting action and not by flooding. There should be very little if any run-down of materials as opposed to the application of silicones mentioned above. Brush, roller or airless spray may be used.

Hydrozo passes the ASTM submersion test with a repellency rating of 98 percent. The coating is resistant to acids, alkali, moisture, salt brine and sunlight. Mineral gum solids will penetrate 1/4th inch or more below surface. The coating has been tested by the National Bureau of Standards (Q.M. 095-S-Std. test report). It has a minimum vapor transmission rate of 5.7 grams per 100 square inches for a 24-hour period which assures breathing. While Hydrozo may be applied at temperatures lower than 55° F., it must be worked into the surface so that no material remains to cause clouding. If clouding does occur, it will disappear with warm weather or a light application of mineral spirits.

Hydrozo has limited use in the Southwest; it should have more use, particularly on surfaces of stone masonry, soil-cement veneer, and capping. Obviously, this gum and mineral based resin will not preserve friable adobe, but it will slow deterioration of adobe walls that are firm at the time of treatment.

HERBICIDES

The use of nonselective herbicides in keeping areas free of weeds, particularly room interiors, has had a brief history in the Southwest. First trials of a wettable powder, "Telvar-W," were made at Chaco Canyon in 1954. This small successful test was followed the next year by application at Aztec Ruins, Tuzigoot, and the Tumacacori National Monuments, and later at Gran Quivira. We are particularly indebted to then Superintendent John Stratton and Archeologist Peck for the careful photographic and written records of results at Tuzigoot. After three years' use, they report excellent results in keeping rooms and other areas clear of local weeds including Russian Thistle, Puncturevine, Arizona Poppy and Trailing Four O'clock. The only vegetation which persisted were small clumps of an unidentified bunch grass. Less complete records from other areas indicate similar success in eradicating local weeds.

The only herbicide which has been well tested by the Stabilization Unit is this wettable powder, "Telvar-W." Numerous other herbicides are on the market, many of which may prove equally effective. Some types containing large percentages of borax, and which require heavy concentrations, were not tested. It was feared that the borax might produce undesirable leaching in masonry walls. Beginning in 1968, the staff at Chaco Canyon turned to the soil sterilant weed killer termed NS-610, a product of the National Chemsearch Corporation. Fast acting, nonselective, and low in toxicity, this product effectively kills all grass and weeds for a full season or longer, and is used successfully in the large open sites at Chaco Canyon. One to two gallons of NS-610 diluted with 10 gallons of water will sterilize 1,000 square feet applied in a coarse, wet spray.

In general, nonselective herbicides act upon the root systems of plants and sterilize the soil for varying periods of time, depending upon the rate of application, porosity of the soil and amount of rainfall. Application after the growing season begins and plants have attained some size is not as effective as applications made at the start of the growing season when plants are in the seedling stage. In any case the manufacturer's directions should be followed for maximum effectiveness.

Herbicides, as described above, are authorized for use in keeping rooms and small areas within sites free of weeds. Their use is far more economical than hand cutting or hoeing. In larger areas where a large expanse of barren ground might be objectionable, consideration should be given to low types of ground cover or sod where

such can be established. In any event, herbicides must be strictly controlled to prevent washing into areas of valuable plantings.

POISONS AND RODENT REPELLENTS

In some archeological locations extensive damage can be caused by rodents, particularly rats and ground squirrels burrowing through or under masonry or adobe walls. Rodents have been particularly destructive in the cliff dwellings at Tonto National Monument where the structures are located in a dry cave, and at the schoolhouse at Tumacacori where the adobe is enclosed within a modern protective structure. Rodents at the schoolhouse had found a protected runway between the original walls and those of the enclosing structure.

In areas of moderate infestation and where the affected structure is somewhat isolated, as at the Tumacacori schoolhouse, poisons are effective. Needless to say, extreme care must be exercised in their use. It is recommended that only those poisons employing a warfarin base be permitted. (Warfarin based rodenticides are stocked by GSA.) The warfarin base has a cumulative effect and must be consumed repeatedly over a period of time to be fatal. Such poisons are not as dangerous as those containing arsenic, strychnine and similar quick-acting ingredients. In any event, the poison should be placed in an approved bait station with a locked cover.

In areas of heavy infestation and in areas where the population is extremely dense in the immediate vicinity, poisons have limited usefulness unless a determined effort is made to reduce the rodent population over a wide area. In such instances the use of poisons should be combined with repellents which act to repel rodents from selected areas. Various areas in the Southwest participated in a recent test of rodent repellents on a small scale; the limited tests indicate that such materials, either in liquid or pellet form, might prove successful. Further tests in confined archeological sites are being continued.

A general list and evaluation of reference material on repellents used to protect pine seedlings is available from the U.S. Department of Agriculture, Pacific Northwest Forest and Range Experiment Station, entitled *Comparison of 2 Rodent Repellents in Broadcast Seeding Douglas-fir*, May 1957.

A note of caution is in order. Pesticides have assumed both national and international significance. Their use and misuse have seriously affected the environment. Before toxic chemicals are employed in an eradication program, including those briefly listed here, the user should consult with State (Agricultural Extension Service) and Federal (Interior) authorities for up-to-date information regarding restrictions, prohibitions, and alternative materials or methods for conducting a pest control program.

4 Techniques and Controls

EROSION FROM CAPILLARY WATER

Capillary water is a term used to designate moisture in walls and fill and is considered as "ordinary water which occurs in small voids so that the surface tension of the water becomes an important factor in determining its behavior" (Plummer and Dore, 1940, p. 59). Use of this term will distinguish it from hygroscopic moisture which surrounds and is closely associated with the individual soil grains and cannot be evaporated by air drying. Gravitational water, on the other hand, is that occurring in sufficiently large amounts to behave according to usual hydraulic laws. Percolation down through fill against a structure might be considered as gravitational water but, for the purpose of handling in ruins stabilization, there is no difference between percolation and capillary water since it rapidly becomes the latter.

This section deals with moisture entering masonry walls either by upward movement of capillary moisture or the outward movement through walls of moisture entrapped in fill areas. Capillary moisture acts either upon the aboriginal soil mortar in the masonry, or upon the softer varieties of sandstone and is one of the major factors in the disintegration of ruins, particularly in excavated sites. It is also one of the most troublesome conditions to control.

The effect of erosion caused by moisture at the base or lower portions of a wall becomes rapidly cumulative. Erosion of narrow but long sections results in severe damage to or loss of higher areas by settling or collapse. The surface disintegration of a masonry wall is caused by the movement of water through it. The damage occurs at the point where the moisture leaves the masonry and comes in contact with the air. Even soft sandstone which is continually damp below ground surface remains in fair condition so long as it is not exposed to alternate cycles of wetting and drying. Where one side of a wall remains damp from contained fill, the damage occurs not on that side but on the opposite side at the point where entrapped moisture comes in contact with the air.

The area of efflorescence and decay may be at some distance above ground level—at the limit of capillary rise from moist soil (fig. 15). It may be toward the upper part of a retained damp fill, or in a protected location where there has been surface absorption from melting snow. For example, the moisture content of a silty-loam fill from within a drained area at Pueblo Bonito was found to be 16 percent in a month when precipitation was less than 1/2 inch (.42). Similar erosion of face stone may be observed in cave sites even though the walls are based on bedrock. Moisture is derived from the drip of melting snow, rainfall, or seepage on the cave floor (fig. 16). Where masonry is constructed of a durable stone, or there is thick bedding of the mortar, this efflorescence first becomes noticeable and more pronounced in the mortar than in the stone.

At open sites in more nothern latitudes, most of the capillary water in soils or structures is de-

rived from melting snow, despite the fact that precipitation from rainfall may be heavier during other seasons of the year. There is little surface movement of this moisture; it is absorbed into the soil or wall immediately upon melting. For this reason, it is extremely difficult to control by ditching, tiling, dry-barreling or other drainage measures.

FIGURE 15. Damage caused by outward movement of moisture from fill behind kiva wall. The most severe disintegration is at the limit of capillary rise, just below the concrete capping. (Clan Kiva, West Ruin, Aztec Ruins National Monument, N. M.)

EVALUATION OF METHODS

Methods employed in the past to prevent moisture from reaching and being absorbed by walls have included 1) surface drainage, 2) subsurface drainage by means of tile and gravel backfills, 3) construction of concrete curtain walls to cut off movement of water, and 4) sealing backs or subsurface portions of walls with impervious coatings.

An evaluation has been made of 21 fill retaining walls which had been repaired by the above methods, individually and in combination. These walls retain from 1/2 to 1 1/2 stories of fill behind them. The evaluation was confined to walls which were in the most hazardous condition, and which were considered to present the greatest problems, i.e., walls which were of soft and poorly cemented sandstones, usually without bedding planes and with little resistance to weathering. Samples of deteriorating stone removed from Pueblo Bonito and oven dried to a constant weight show moisture content of from 4 to 26 percent. Thirty percent is the theoretical limit for sandstones. Only walls where erosion from capillary moisture took effect near the base or center of the wall were considered. Areas that required only capping were excluded.

Of these 21 fill-retaining walls, 13 remained in good to excellent condition after a period of 10 to 15 years. Eight showed moisture absorption in varying degrees, from small damp spots that appeared during the winter to four examples where it has been necessary to replace disintegrated stone. Eleven of the 13 walls in good condition were so located that it was necessary to provide drainage lines through the walls to the exterior. The other two were in graded areas. Seven were treated after repair by the application of a seal coating on the reverse or fill side. Eight of the 11 drains were still operative. Three had become filled with drifted sand.

Walls that remained in the very best condition were those six which were sealed off from the moisture in the retained fill by a coating of impervious material, and where the drainage remained operative. It is this combination of factors—prevention of moisture absorption from the banked fill, and removal of surface moisture on the face side—which gives the best results. Of the remaining seven walls in good condition, one had been seal coated on the reverse side but the drainage plugged, as it was in two other instances. Drainage remained open in two, and the last two of the 13 had required grading only. All of these walls are in good condition, but they do not show the absolute freedom from moisture as do the six where seal coating was combined with drainage maintenance.

Of the remaining eight walls, four with large damp areas and four requiring repair, only two have been provided with surface drains; both became inoperative. None had been seal coated.

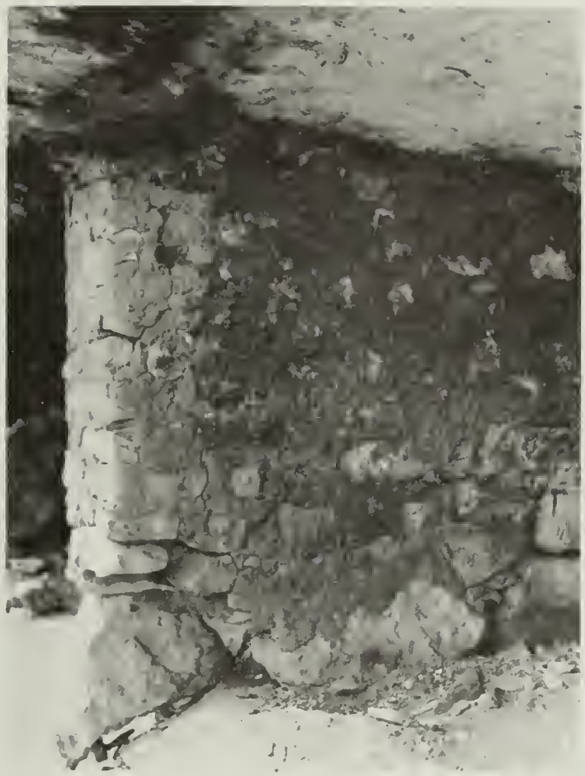


FIGURE 16. Damage as the result of rising moisture from melting snow. Note that decay is confined to the limit of capillary rise in the mortar column. (Cliff dwelling in Walnut Canyon National Monument, Ariz.)

Thus, the eight poorest examples lacked both drainage and seal coating. Six of these eight walls were not provided with drainage to the outside because of location (deep rooms enclosed on all four sides by two or three rooms of fill). Of these six, four were provided with a measure of subsurface drainage—backfilling against the base of the wall with gravel and then broken rock. This proved to be inefficient. Considerable windborne material has drifted over this gravel backfill since it was laid.

A similar evaluation was made of 19 walls (not retaining fill) constructed of and repaired with the same class of soft stone as in the 21 tested which retained fill. Fifteen remained in good condition. Four showed large wet areas where failure of drainage lines had impounded water (figs. 17 and 18).

In the testing and evaluation of methods for the control of erosion by capillary water, experimental walls were constructed using various techniques and mortar materials. The tests were conducted on square areas that could be filled with wet soil and kept damp in accelerated weathering. They have shown the following results:

1. In the treatment of stone, the soft friable specimens laid in the wall were treated with several commercial masonry waterproofings. (These were types for below-ground masonry and are not to be confused with above-ground repellents employing silicones.) Clear types did not prove effective; heavier, opaque types such as "Aquella" painted on all but the exposed surface proved effective in preventing moisture absorption into the facing stone. Such treatment is time-consuming, and the opaque types are difficult to use because the treatment must be withheld from exposed portions of individual stones.

2. A test for moisture resistance was made with concrete mortar containing an emulsified asphalt "hydropel." Care was taken to completely embed the stone (except for the exposed face) in this treated mortar, and to avoid stone-to-stone contact. A similar method was employed in setting a patch in a continuously damp

FIGURE 17. Basal erosion from capillary moisture is particularly damaging in the interiors of excavated sites where drainage is poor. (West Ruin, Aztec Ruins National Monument, Ariz.)

ruin wall. In the test and in the ruin there was no moisture absorption through the mortar into the stone. The treated mortar is more resistant than plain concrete, and there appears to be no movement of moisture along the line of bond between stone and mortar.

3. In stone laid in soil-bitumen mortar, failure became evident first at the base, the area of greatest moisture penetration. The stone became

FIGURE 18. The severe undermining and basal erosion of a wall resulting from capillary moisture. If left untreated, such walls soon collapse. (West Ruin, Aztec Ruins National Monument, N. M.)

damp and there was progressive disintegration of the surface. Despite the condition of the stone, the soil-bitumen mortar remained hard and dry. It is evident that penetration of moisture was due to lack of bond between the mortar and the stone.

4. In stone set in ordinary concrete mortar there was some moisture penetration; stone at the base became damp and there was some disintegration of the surface. The mortar also became damp; it was evident that moisture had moved through the mortar into the stone.

In summary, the results of field use and accelerated weathering tests indicate that maximum control of percolating moisture from entrapped fill and the rise of capillary moisture is achieved only by a combination of several procedures: 1) sealing of the wall as effectively as possible from the moisture-bearing soil, 2) the maintenance of proper drainage, and 3) the employment of a moisture-resistant mortar. Specially treated mortars were the most resistant. Ordinary concrete mortar permitted the passage of some moisture, and soil-bitumen mortar was unsatisfactory. No tests were made on soil-cement mortars, but work subsequent to the weathering test indicates that thin mortars of soil-cement would be no more resistant to the passage of moisture than was the soil-bitumen, and that such mortars also would prove unsatisfactory for this specialized application.

CONTROL OF CAPILLARY MOISTURE

The use either of a concrete mortar whose water resistant qualities have been increased by the addition of an emulsified asphalt similar to "hydropel," or of special waterproof cements, is recommended (Plastic, Medusa, or equal). In either case the manufacturer's recommendations should be followed. In the case of "hydropel" 1 1/2 gallons per sack of cement are used.

Waterproofing

For a workable mixture, the water or liquid-cement ratio should be kept at not more than six gallons per sack of cement. This liquid is to include the "hydropel" or other emulsified asphalt. In all probability, the liquid-cement ratio can be reduced below the 6-gallon limit due to increased workability obtained with the asphalt admixture. The asphalt is added at the time of mixing.

There is a great variation in type and gradation of sands. It is advisable therefore to make trial mixes to determine accurately the sand-cement ratio requirements. In many areas, mortar sand, as opposed to concrete sand, can be obtained from commercial sources. The ratio will probably range from 1 to 2 1/2 for the more finely graded. Sand should be clean and free from inclusions of dirt or organic impurities. Mortar should be thoroughly mixed. Thorough mixing improves the plasticity and workability; less mixing water is required to obtain proper working consistency when the mixing time is increased.

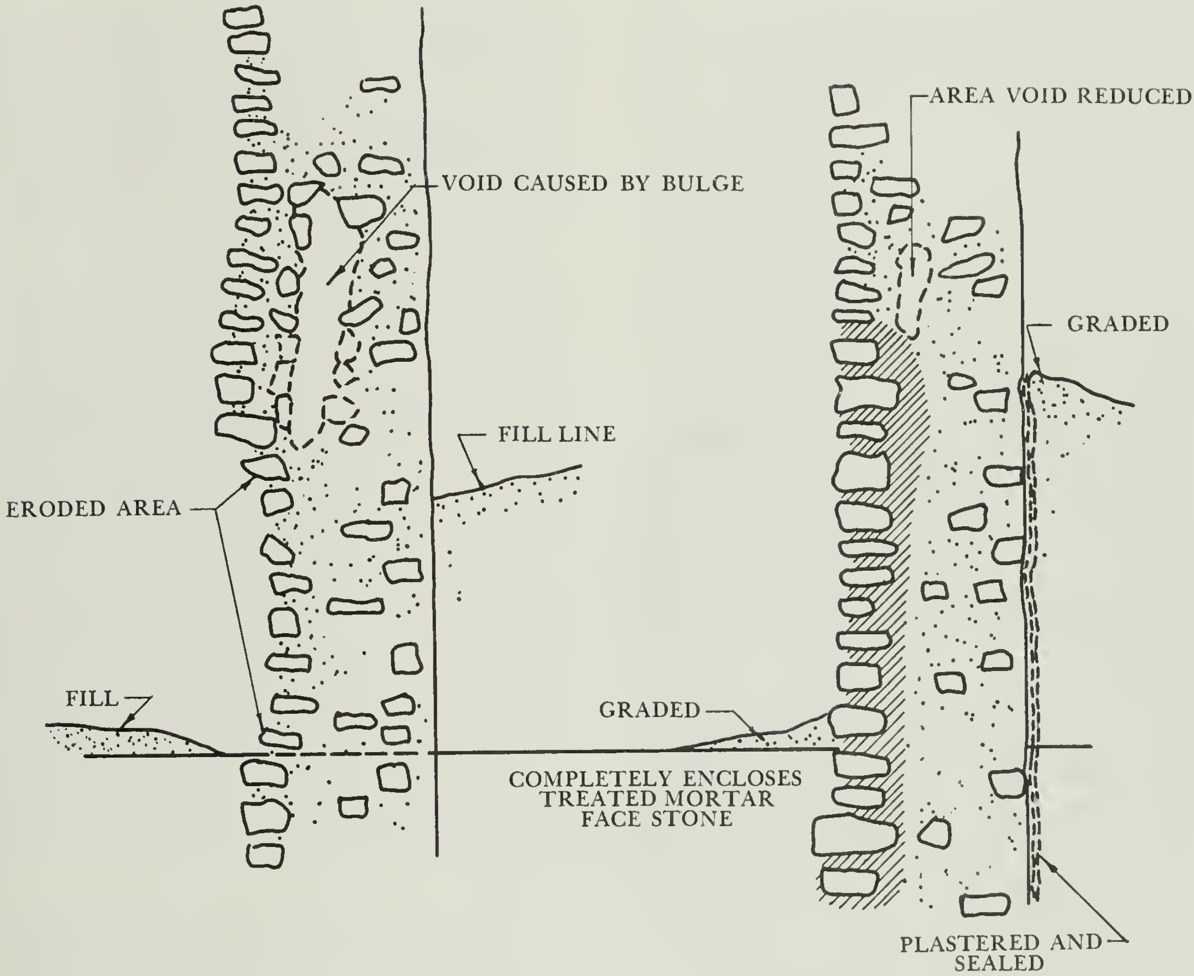


FIGURE 19. Field control of moisture erosion. Wall depicted in section at left before treatment; following stabilization at right.

Placement

In laying out stabilization for a wall deteriorating from moisture erosion, consideration must be given to any proposed changes in the fill level (fig. 19). Where the eroded wall also retains fill, the treated mortar should extend somewhat higher than the eroded area to insure against possible increases in the capillary rise. Thus, it is better to include too much rather than too little mortar in the area stabilized. While this might violate the precept of keeping the replacement of prehistoric or original material at a minimum, it is desirable that the replacement be made all at one time rather than over a period of years, as moisture works its way around too small a patch.

If breakdown of the lower wall areas has proceeded over any period of time, possible faults in the surface above these areas will also have to be taken into consideration. Cracks, bulged areas, and separation of courses due to settling are apt to occur. Furthermore, where erosion has cut into the wall some distance it may be possible to reface the surface using thin stone or other original material without removing the deteriorated area. This is not a profitable undertaking. It will not permit the use of a heavy mortar bed, and little support is given the upper levels of the structure since a thin patch cannot be tied securely to the original work.

Defective masonry must be removed in narrow vertical sections. Some experience is required to determine the amount that can safely be taken out at one time. This is dependent upon the general type of construction and condition of the structure. It is seldom advisable to use jacks and blocking to remove large sections at one time. Removal of stone is best accomplished by cutting the mortar with a cape chisel or other sharp tool, and prying rather than attempting to break or knock material out with a hammer. Since vibrations are easily transmitted, bond in adjacent sections is apt to be broken.

Before setting stone, dampen it thoroughly. This helps remove the film of dirt which interferes with the bond and, particularly in hot weather, the absorbed moisture aids in setting the mortar. Do not smooth the mortar bed unduly but leave it slightly furrowed so that it will meet irregularities in the stone. The stone can be tapped into place with the handle of a mason's hammer.

On finely surfaced walls, the joints between facing stone are often filled with small spalls. Some masons have a tendency to drive the spalls into the joint after the larger stone has been set. Do not permit this. It will raise the larger stone out of the mortar bed and spoil the bond. If spalls of any size are used, they must be set in the mortar first and the upper stone set in place over them. This procedure is time consuming, since it is difficult to clean the extruded mortar from small spalls.

Treatment of Oblique Surfaces

The most frequent result of moisture erosion in the upper levels of heavy walls retaining fill is loss of the facing on the exposed side. This results in an irregular and oblique surface. There are two alternatives in stabilizing these areas: 1) either the missing face of the wall can be rebuilt and sealed off from the damp fill, or 2) the broken slope can be taken down and relaid in a moisture-resistant mortar, and soil-cement pointed for appearance. Rebuilding the missing face is more time consuming and expensive, but it is sometimes advisable where the wall is in very bad condition or the additional strength is needed to buttress adjoining walls.

Relaying the oblique surface in a moisture-resistant cement mortar is more effective from the point of general appearance (fig. 20). The only drawback to this method is that large areas of the waterproofed mortar will be exposed. It is difficult, if not impossible, to color cement mortars containing emulsified asphalt. Special waterproof cements, however, can be colored.

Where the extent of exposed mortar is not too great, the appearance can be greatly improved by holding the concrete back 1/2 to 3/4ths inch from the final surface, and pointing to this depth with stiff soil mortar. The appearance of the soil pointing will be much more satisfactory than that which can be obtained with concrete mortars. The soil pointing will require replacement after a few years, but it is an easy job which can be accomplished by unskilled labor and with little supervision. This technique was first used extensively by Earl Morris at Mesa Verde during 1934, though he undoubtedly developed it earlier (Hamilton and Kittredge, 1935, pp. 1-14). It is a particularly valuable method of retaining appearance while employing durable and moisture-resistant materials in the body of the structure. It can be used in many applications where soil, soft lime, or other distinctive mortars are widely exposed.

In resetting stone on an oblique face it is best to lay the work out in vertical strips rather than in horizontal sections. This aids in maintaining the slope, and it is easier to match the pattern of the adjacent surface. The same method as that used in setting repairs in the face is employed—each exposed face stone is well bedded in the treated concrete mortar. This will mean that the entire vertical section must be taken down and relaid, rather than merely cleaning out the soil mortar and grouting the interstices with mortar. Depth of mortar will vary with the height of the wall and the size of stone used, but it is suggested that a thickness of 6 inches be taken as a minimum.

The point of greatest weakness in such an installation is at the bottom where the slope joins the remaining vertical face (if any) of the wall. At this point the vertical face must be taken down and the upper three to four courses reset in the

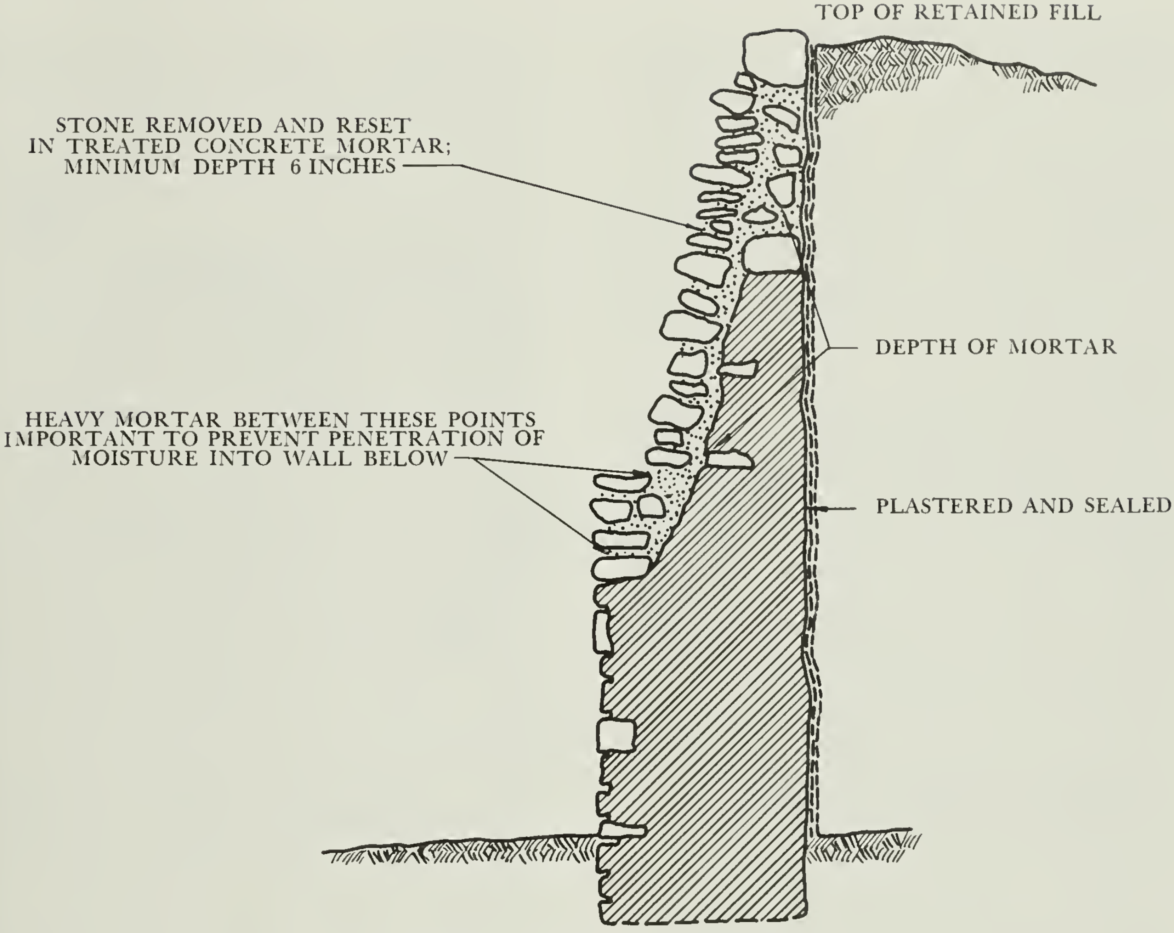


FIGURE 20. The application of waterproofed cement mortar to an oblique wall.

water-resistant mortar. Extra care must be taken at this point to prevent accumulated water from the slope entering the lower wall.

Seal Coats

While the employment of water-resistant mortars combined with surface drainage will aid materially in the reduction of moisture-absorption in many situations, this procedure should always be carried out in connection with sealing off the reverse side of the wall wherever possible. To be effective, the sealed area must extend well below the level of the exposed and eroded area. Difficulties encountered include work on irregular surfaces, breaks or holes in the surface to be sealed, and adjoining or abutting structures.

Extensive sealing-off of wall areas is more often required in excavated sites than in unexcavated areas due to the more porous nature of the fill in the former. The application of an impervious seal coat for the reverse covered side of a wall will spoil it for future exhibition. This is seldom, if ever, a consideration in excavated sites. Extensive areas were sealed off in the mission structures of San Isidro and San Buenaventura at Gran Quivira. In both instances no future excavations were contemplated.

The purpose of sealing off portions of a wall is to prevent the entrance of moisture into the wall from enclosed fill or from higher levels outside the site where the structure is partially subterranean. The procedure is much the same as that

employed in making basements waterproof. The area against the wall must be excavated, and any abutting walls or portions of structures removed.

Prehistoric walls with soil mortar do not present a sufficiently sound surface on which to work. When the wall is cleaned of loose and friable material, it should be plastered with a sound cement plaster, one or two coats as required. Care must be taken to cure this properly so that no cracks develop. After the plaster has cured, it is treated with applications of hot asphalt or an approved asphalt foundation paint.

When the area against a sealed surface is backfilled, some effort must be made to compact the fill near original density, and to provide surface drainage. In a recent project (1970) at Tumacacori National Monument where the walls of the Mission Church were successfully damp-proofed, a sealant and a liner were employed as follows: 1) exterior foundations were trenched; 2) the rubble stone masonry foundation walls were grouted and pargeted; 3) after curing, the pargeted surfaces were waterproofed by a trowelled-on membrane at a 60 mil thickness, using Thiokol 411-H Elastometric membrane. This is a trade name for a two-component, chemically-curing liquid polysulfide based waterproofing compound, specifically formulated for manual mixing and application by troweling, brushing, or squeegee. The compound is easily applied without heating, and cures at an ambient temperature of about 40° F. to form a highly flexible, seamless, rubbery membrane impervious to water. While the Thiokol was still damp, a 20 mil. Polyvinyl Chloride (PVC) liner was laid across the bottom of the trench and up the Thiokol-covered wall. The PVC was used in the 24-foot width. Two feet of PVC rested on the bottom of the trench, 4 feet were adhered against the wall, and the remaining 18 feet were rolled up on temporary supports while the trench was backfilled. The PVC was then sealed to the plastered foundation with a 3-inch-wide band of PVC-to-concrete adhesive applied above the Thiokol. All overlapping sections of PVC were sealed to each other with PVC-to-PVC adhesive. A 20-foot area from the wall was then graded with a front end loader to provide drainage away from the wall. The remaining 18 feet of PVC was unrolled and spread over the graded area and backfilled with local soil. The PVC is buried about 6 inches below grade at the wall, and 18 inches where the graded area joins the ditch leading surface water away from the Mission.

At Fort Bowie, the clayey, impervious soil and standing water required other procedures engineered to local conditions to combat dampness and capillarity in unprotected adobe wall remnants. These systems have functioned very well since installation in 1965. Briefly noted, the foundations were pargeted and treated with asphalt emulsion. Before backfilling the trenches, a drainage system was installed by laying perforated asphalt pipe covered with gravel. The pipes were pitched to inconspicuous outlets beyond the structures. In another instance, a long interior room was drained by laying a polyethylene liner several inches below grade over the entire "floor," and a perforated pipe laid along the center of the long axis of the room after it had been graded or pitched slightly to the center and to one end. The pipe extends beneath one wall and exits at an inconspicuous outlet. The floor-liner method of halting capillary action was used successfully in open sites at Mesa Verde and other areas where bedrock is close to the surface, and where other related drainage measures are not feasible.

RELATED DRAINAGE

Discussed here are drainage problems relating to removal of surface water from areas treated as above, and also the removal of surface water from all areas within a site. Drainage over large, relatively level areas of a site is seldom a problem except, perhaps, in large plazas. In most Pueblo sites, surface water within rooms is absorbed into the soil and presents little difficulty. Problems are encountered where adjacent rooms or small areas are at widely varying levels, and where there is either surface washing from one level to another, or moisture penetration through a wall.

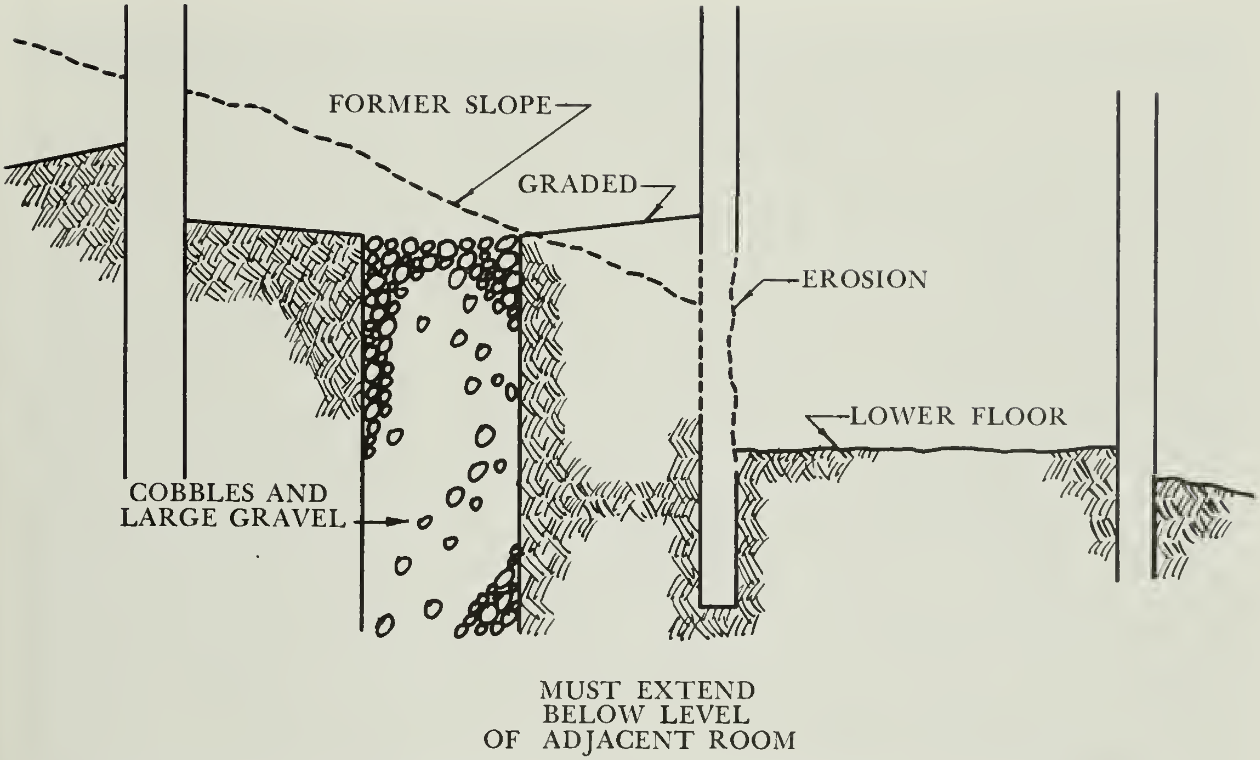


FIGURE 21. Construction of a dry-barrel (in section). Note that it has been carried well below the adjacent floor levels.

Dry-Barreling

The use of dry-barrels is suggested for enclosed areas where drainage lines to an exterior point would be difficult to construct and maintain. The purpose of a dry-barrel is to quickly drain water falling into a room to a level below that at which it can cause damage by percolation into adjoining areas.

A dry-barrel is usually constructed at the center of a room or confined space (fig. 21). A circular hole 3 to 4 feet in diameter is dug to a depth which is at least 3 feet below the lowest level in adjoining rooms. The hole is then backfilled with random stone or gravel with fairly well graded material at the top to prevent the entrance of large amounts of silt or fine material. The surrounding surface is graded to the sides of the dry-barrel.

Surface Drains

It has become apparent after years of experience that surface drainage presents some unusual problems in maintenance that are not encountered in ordinary structures. Surface drainage systems are often employed in sites or portions of sites that do not receive regular maintenance. Change of personnel in areas results in total lack of information on the nature and location of drains. Drainage lines often become rodent burrows, and interpretive personnel will frequently cover the open ends of drains to hide them, a practice that usually results in complete stoppage. With this in mind, very careful consideration must be given to laying out any drainage system. Small individual drains running to open areas are far better than large systems draining several rooms and areas together. The larger the

system, or the more rooms that are drained together, the greater is the chance of damage when one section of the system becomes inoperative. Tile drains with vertical sections and elbows connected to horizontal runs are to be avoided. Soil in most sites is loose; there is always an abundance of blowing sand or cinder, and such drains become easily clogged.

The preferred drain is one with a small concrete settling box covered with a grate, the tile line extending from the side of the settling box (fig. 22). Tile lines through walls are preferred to "weep holes," in spite of the fact that their appearance is not as satisfactory. Weep holes tend to admit water into the masonry unless very well constructed. While the necessities of appearance would seem to dictate concealed or very unobtrusive lines emptying from a small area, annual inspection of numerous sites has demonstrated that such lines are simply not maintained, and that an obtrusive line which empties surface water from an area provides far better protection than a concealed line which has become inoperative through accumulations of sand or cinders.

REPAIR OF WALL BREAKS

The discussion here will deal with the stabilization of masonry walls containing ordinary structural failures—loose areas, holes entirely through the wall, or holes which extend only part way through as are often found in heavy structures of veneered construction.

At least 50 percent of the repair in the Southwest will be done with stone of some type. That used in setting a patch should match stone in the original wall as closely as possible. There is little chance that the requirement that a patch be discernible upon close inspection will not be met, since it is practically impossible to construct one that cannot be located by expert inspection.

Stone from the ground in the vicinity of a site, as opposed to that saved from an excavation, would ordinarily seem to meet the requirements. However, stone which has been exposed on the ground for centuries is sometimes not the best. If it is porous, e.g., a soft sandstone, it is no doubt partially disintegrated. Where walls must be repaired with faced stone of the softer varieties, it is usually a major problem to locate useable pieces. In some cases, replacement of pecked or dimpled stone will require an exhorbitant amount of time to properly shape and surface the individual stones (fig. 23). Porous stone often absorbs salts from the soil in which it lies. After the stone is set in a wall and has become damp and then dried a few times, these salts will leach out and mark the patch as a white area.

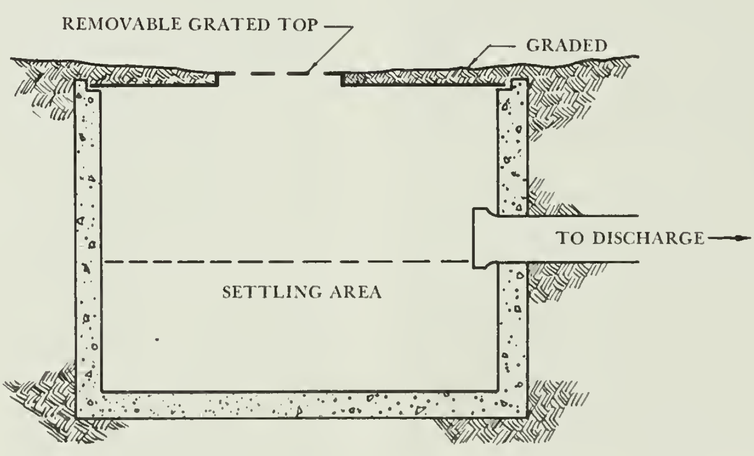


FIGURE 22. A settling type inlet for drain lines.

FIGURE 23. An example of soft, pecked and dimpled stone in random areas over wall surface. Replacement of the stone requires extreme care if the character of the wall is not to be changed. (Peñasco Blanco Ruin, Chaco Canyon National Monument, N. M.)

Small spalls are also difficult to find and are rarely, if ever, saved from an excavation. Time can be saved if suitable rock and spalls are quarried. Useable quarries can often be located close to the work, and a single truckload of spalls will save much time and effort searching for individual pieces.

Patching Simple Wall Breaks

Determining the cause of a break in the first place will be of some help in planning repairs and to prevent a recurrence. This is particularly true when the forces that result in the break are still active and must be counteracted before the patch will be effective.

Two of the most common types of simple breaks are those caused by breakdown or removal of some wood member, rotting, excessive weight, or vandalism; and disintegration of soil mortar where it forms a major part of the wall.

Breaks often become enlarged over the years so that it is difficult to determine just how they start. This poses a problem if plans are made to fill the hole completely with repair masonry. One should always ask whether such holes should be filled in solid, or whether there was once a doorway, small opening, or a beam socket.

Doorways were often partially filled during the time of occupancy. Close examination of the masonry remaining in the bottom of the break

FIGURE 24. Wall break in a partially excavated site. A patch must be designed to prevent further flow of water and fill at the top, and some excavation will be required to base patch on sound masonry. (East Ruin, Aztec Ruins National Monument, N. M.)

will sometimes provide evidence of an opening. Removing a few stones may reveal the side or jamb of a door. Changes in masonry style are another indication of filled openings. Within a room, examination of an opposite wall will sometimes serve to indicate the position of beam sockets.

In placing a patch, care must be taken to clean the masonry surface surrounding the break (fig. 24). All loose stone and unsound mortar should be removed. This might necessitate excavating around it to a depth of several feet. In large sites, if the bottom of the break cannot be reached for one reason or another, the base of the patch should be laid in reinforced concrete to form as good a footing as possible. There are only two essential requirements, i.e., the patch should be laid in the same type of stone and in the same pattern as the adjoining wall, and it must be tight. Excessive shrinkage is apt to cause the most trouble in soil-mortar patches. If this is likely to be a problem, it is best to use cement or masonry mortar. The stone placed in the patch must be clean and damp. A film of dirt prevents bonding with any kind of mortar. The masonry adjacent to the patch must also be clean and damp for the same reason. Whisk brooms can be used for dampening the original masonry; the fine spray of a back pack pump gives excellent results.

FIGURE 25. Repair at the position of the arrows will be based on a very small area in comparison with the total size of break. Every effort should be made to tie such patches securely to the existing wall. (Pueblo del Arroyo Ruin, Room 14, north wall, Chaco Canyon National Monument, N. M.)

In a great number of cases there will be as much mortar exposed on the wall face as there is stone. In anything but soil mortar, slick trowel marks will show as long as the mortar lasts. The best way to obliterate tool marks is with a whisk broom or by hand, before the mortar has begun to set; if left they will certainly spoil the appearance of the job.

In cases where colored soil-cement or concrete mortars are used, the matter of troweling is also important. Troweling of colored mortars results in a thin film of the color on the surface and also produces a reflective surface. It must be remembered, particularly with colored mortars, to rake or scratch thin mortar joints and brush large areas after the mortar has dried, but before it has set hard. The most effective method of retaining good appearance is to point the surface with soil mortar.

Doorways and Large Openings

Breaks in doorways and other large openings usually take the form of an inverted triangle, the apex of which is at the bottom and the greatest breadth higher in the wall (fig. 25). In repairing such openings, one is tempted to replace only the missng stone. But unless the material is of large size and the wall exceptionally clean, this is apt to be a poor investment in labor and materials. The bond between stone and mortar in prehistoric walls is weak. At best, the replaced stone will not bond well with the original work, due largely to the amount of soil mortar exposed in the interior of the wall. This results in a patch of one solid unit, an inverted triangle, and in too little bond with the remainder of the wall. When such patches fail they do not break up, but separate in one piece from the structure. It is therefore better to remove sufficient original material to reset it in a patch, the base of which is somewhat larger than the base of the original break, and which will be stable in itself and without dependence upon the bond with the original work.

Slumped and Filled Areas

An effective method of handling small slumped or loose areas was developed at Wupatki National Monument by A. E. Buchenberg. Here small vertical sections of the slumped areas were cleaned of soil mortar; cement or soil-cement mortar was packed between the stone. This makes an authentic appearing repair, provided

FIGURE 26. Deep grouting with soil-cement on the badly weathered face of this cobblestone wall will not change its appearance, but will halt the rapid rate of erosion. (East Ruin, Aztec Ruins National Monument, N. M.)

the color and texture of the replaced mortar is not too conspicuous. To be effective, the grout must extend from 1/4th to 1/3rd of the way through the wall. This is particularly true with soil-cement mortars. Grouting in an area of slumped stone keeps a ruin looking like a ruin instead of an unfinished building, and it is far cheaper in labor and material than the alternative of replacing the entire section.

Vertical Surfaces

Vertical wall areas containing an excess of soil mortar at the surface often become badly weathered, while the interior of the wall remains sound. Large wall sections can be saved and future repairs extensively reduced by grouting between the exposed surface stone (fig. 26). The same cautions must be exercised here as noted above. Loose soil mortar must be removed and

FIGURE 27. Scaffolding in place at completion of respalling and grouting large wall surfaces. (Wukoki Ruin, Wupatki National Monument, Ariz.)

sufficient depth obtained so that there will be some bond between stone and mortar.

Respalling

Where masonry walls containing a large proportion of spalls or chinking on the surface are subject to extreme weathering in exposed locations, surface repair may become a time-consuming project. As the spalling is lost to weathering, the soil mortar between individual stones is then exposed. It weathers far more rapidly than did the spalling, and decay of the wall is accelerated. Loose and softened soil mortar must be scraped from between the individual stones, the space then partially filled with cement mortar and the spalls tapped into place in the mortar. Large walls require considerable equipment and an experienced crew (fig. 27).

Break Where Weight is a Factor

Considered here are partially displaced or shattered areas which still furnish some measure of support, but which must be removed in order to effect repairs. In general, the same precautions pertaining to other stabilization apply with added force: repair work must be laid in a high strength concrete or masonry cement mortar and based on sound foundation; the edges of the adjoining original work must be clean, sound and dampened; and all replaced stone must be firmly seated in the mortar.

Temporary Support

A fairly common situation encountered involves heavy walls (figs. 28, 29, and 30) in which one side has been broken away due to excess weight or shifting of the upper structure. The problem involves support of the sound part of the structure while removing and replacing the damaged area. This can usually be accomplished with the use of jacks and timber blocking. It might involve cutting a narrow vertical section in the displaced portion in which to place the supports. Since construction and soundness of walls

FIGURE 28. The temporary support of a heavy wall with timber. The arch at lower right was constructed in the 1920's as a repair measure. The first step in stabilization involved the placing of a beam through a hole adjacent to the arch. Not of aboriginal origin, the arch was subsequently removed. (Room 1, Chettro Kettle Ruin, Chaco Canyon National Monument, N. M.)

FIGURE 29. A second beam resting on jacks is placed through the wall depicted in figure 28. Arrows indicate extent of steel plates above the beam. The area of settling was reduced with upward pressure.

FIGURE 30. Jacks and beams provide support of wall depicted in figures 28 and 29 while arch section is removed. The break is filled with repair masonry.

FIGURE 31. Placement of jack in line with shattered facing near the bottom of a 14-foot wall. The jack provided support while the broken area at the right was being replaced. (Chettro Kettle Ruin, Chaco Canyon National Monument, N. M.)

varies from room to room in a single site, and no two situations are identical, only general suggestions can be given for temporary support of walls during stabilization as follows:

1. Only screw-type jacks should be employed. Do not try to use ratchet jacks.

2. Solid foundations must be provided. Never place a jack on top of an upright timber; use cribwork to reach the desired height.

3. Neither the base nor the head of the jack should bear directly against the masonry. Both must be separated from it by means of steel plates (or wood blocking in temporary installations) and cement grout.

The use of plates greatly increases the bearing surface and permits support of more than one stone. A layer of cement grout at proportions of 1-to-1 will take up inequalities in the stone or between several stones and provide an even distribution of force. Due to the irregular nature of building stone, it is usually impossible to seat a jack squarely against it anyway. In some cases, especially in small areas, it will be impossible to

support breaks by extending beams through tne wall, and it will be necessary to place jacks within the break itself (fig. 31). In either veneered or single-width walls, examination will indicate the approximate centerline of masonry to be supported. The jack must be placed as nearly as possible in this line. A variation toward the center of the wall will tip the above masonry downward and out when force is applied. Conversely, if the jack is too far out, pressure will act toward the center of the wall and tend to kick the jack out of place.

Once the jack is placed with plates and grout, it can be run up with light pressure until the plates are evenly forced against the masonry and some grout is extruded. With the grout conforming to the shape of the supported masonry, allow sufficient time (at least 24 hours) for it to gain an initial set before more pressure is applied. Always take your time when setting jacks. If more than one is to be used, set them on succeeding days. While temporary jacks are in place, they should be tested frequently. The grout will shrink slightly as it sets; if wood blocking is used it will be somewhat compressed. Cribwork resting on soil will settle. The jacks must be taken up to compensate for all this shrinkage.

Permanent Support

Due to limitations of space or the nature of the wall break, it will sometimes be more satisfactory to install jacks permanently. This is also a quick method of providing support when a section of masonry has been taken down. The requirements here are much the same as for temporary installations, except that wood blocking cannot be used. Once the jack has been set for permanent installations, masonry can be built around it and up to the level of the screw. Before placing a full load on the jack, wait until both the grout and masonry have set.

The amount of pressure one should exert with jacks in both permanent and temporary installations is somewhat of a problem. Masonry weighs about 120 pounds per cubic foot. A column of masonry 12 feet high, 1.5 feet thick, and 2 feet wide will weigh a little over 2 tons. Since this column has some support of its own, it is doubtful that more than half the weight, or 1 ton, will come completely on the jack. A jack with a screw 1 inch in diameter has a capacity of 5 tons; one with a screw 2 inches in diameter has a 20-ton capacity. This might give some indication of how much weight is being taken up. Probably the best procedure is to take the jack up a slight amount each day and carefully examine the wall above for signs of movement.

Somewhat the same procedure as outlined above for small areas can be employed in supporting large sections of wall where the entire width must be removed. This is also a useful method of support where large horizontal timbers are to be replaced with cast members (fig. 32). In supporting large and heavy sections, it is best to run large timbers or steel beams entirely through the wall, supporting the ends with jacks. All precautions listed above for other temporary support should be followed in regard to placement, grouting between the supports and the masonry, cribwork bases for the jacks and frequent compensation for settlement.

Working conditions are often made safer by external bracing against bulged or shattered areas. Jacks with timber set in sleeves are much more satisfactory than timbers alone, as the use of jacks allows some force to be applied to the surface. Timbers alone will not take up much stress until there has been some movement of the structure against them. To be effective, pressure must be applied at the point of greatest movement or distortion.

REALIGNMENT

Realignment of distorted, out-of-plumb walls is seldom practicable unless the wall is in otherwise good condition (figs. 33, 34, and 35). If the wall has to be realigned and is in poor condition, it must first be strongly repaired with a soil mortar. Do not repair the wall with cement or stabilized soil mortars. Considerable time, care, and equipment are required to realign a wall of any size. The general requirements are, first, that the wall must be completely formed on both sides and, secondly, that it be thoroughly damp if it is not to be cracked further or distorted in some other directions. The steps taken should include:

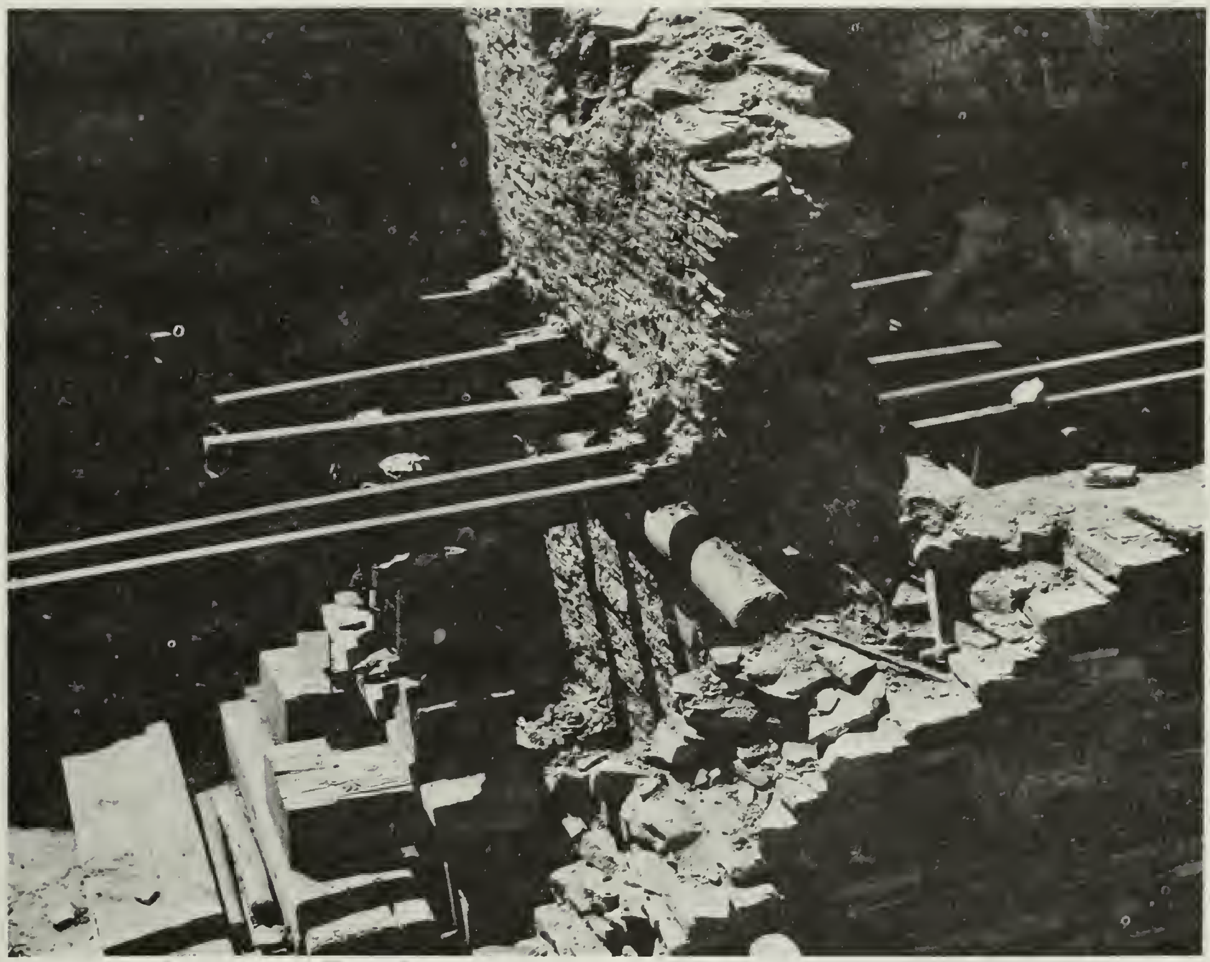


FIGURE 32. A temporary support. Six steel beams buttress the upper half of the wall while a decayed horizontal timber is replaced. The timber is partly removed here. With care, steel beams can be run through pole sockets or other natural openings without damage to the wall. (Chettro Kettle Ruin, Chaco Canyon National Monument, N. M.)

1. Before any work is done, run small holes through the base of the wall to tie the two sides of the form together with wire or thin bolts.

2. Construct heavy forms of 2-inch lumber large enough to completely cover the area to be moved. Line the inside of these forms with asphalt building paper.

3. Set up the forms; leave a space of between 2 to 3 inches between each form and the surface of the wall. Tie the forms both top and bottom.

4. Pack this space with wet sand. Be sure there are no voids. Cover the top of the wall also. Begin to keep this sand continually wet. This requires time and patience. *Do not flood the wall* in order to hurry the process, as this will wash out the soil mortar instead of dampening it. Allow from 3 weeks to a month to dampen a wall 2 feet thick.

5. While the wall is being dampened, set deadmen or other supports against which the jacks can be placed. Timbers in sleeves are necessary to keep the jacks in alignment. Mine jacks may also be effective.

6. After the wall is damp, apply pressure with

the jacks gradually. Mark the top of the form and set stakes or other points so that movement in the wall can be measured. It will require from 2 to 3 weeks to straighten a wall. *Do not try to hurry it.* There will be some compression in the forms and timbers, and settlement of the deadmen. Additional blocking behind the jacks will be required.

7. After the wall is straight, allow it to remain in the forms for another week or two to start drying while it is still supported.

REPAIRING WALL FEATURES

Crushed, sagging, or rotted wood members will often be found in place over open or filled doorways, windows, or other openings. Little can be done for low and narrow walls except to remove the timbers and replace them, either with wood or cast members. Rebuild the wall where necessary. Where wood is the replacing material, some reinforcing effort must be made. In short spans, steel plates may be set above the lintels. In longer spans the wall above the wood must be set in reinforced concrete mortar. In any case, the steps are the same (fig. 36):

1. Masonry above the lintel must be removed for the entire width of the opening, plus at least 6 additional inches beyond each end of the new lintel. In thick walls, one side may be completed first and the other side after this has set.

FIGURE 33. Beginning realignment. Cables have been placed through the base of the wall to be tied to the jacks. Note bolt, lower right, for holding frame against wall. (Pueblo Bonito, Chaco Canyon National Monument, N. M.)

FIGURE 34. Realignment of wall depicted in figure 33. The framework is in place on both sides and is tied together. Frame lined with asphalt paper, space between frame and wall packed with sand. Note that the five screw jacks in sleeves bear against a 4 x 4 timber to distribute pressure.

2. Place the new lintel above the opening after the sides have been repaired; build up the masonry at the ends until it is slightly above the level of the new lintel.

3. If plates are used, lay them over the wood but make certain the ends rest on the masonry at the end and not on the wood. If a reinforced section is used, run a thin layer of concrete mortar over the wood. Embed reinforcing steel in this, likewise making sure the steel and concrete extend beyond the ends of the wood. Complete filling the space above the lintel with masonry set in concrete mortar. The amount of reinforcing and height of the concrete band will be determined by the span of the opening.

Support With Wood Members in Place

If cracked or decayed timbers are found above an opening which has been partially or completely filled in prehistoric times, it is best to leave the outside poles in place and base the repair masonry on the fill, carrying it up through the center of the wall. The exterior poles or lintels are left for appearance only. The steps in stabilizing such an area are:

1. Repair the prehistoric fill in the doorway up to the level of the wood which is to be left in place. Make a small hole at one side of the opening above the outside timber deep enough to expose the interior lintels.

2. Cut out sections of the interior lintels. The length to be removed will depend on the span of the opening and the condition of the wall above. One-third to one-half of the total length may be removed at one time. In large openings, or where the wall is particularly unstable, one-fifth or one-fourth is sufficient. Lintels are most easily removed by a combination of drilling a row of holes across them and sawing between these holes, rather than chopping or chiseling them out. Pounding on them is apt to bring down most of the wall in fragile areas.

3. With one-third or so of the lintel out, build up a vertical section of repair masonry from the patched fill below to the original wall above.

4. After this has set, repeat the process of cutting out a section of the interior lintels and bring the repair up behind the outside lintel.

Beam and Pole Sockets

A great deal of prehistoric construction seems to have followed the following course: (1) the walls were raised to ceiling height and the vigas laid; (2) these were covered with small poles or savinos and on top went the matting, split cedar, bark, or whatever was handy; (3) this in turn was covered with soil for the next floor; and (4) after this ceiling and floor combination was laid, the walls were raised for the next story.

This sequence, with the ceiling and floor finished before another story was added, often resulted in 1) the upper story set back; 2) the upper story overhanging the first, or a combination of the two, i.e., set back at one end of the room and overhanging at the other; and 3) a weakened strip where the ceiling material and dirt floor extended into the wall. Quite often there is no continuous contact of the masonry vertically from one room to that above—rather there is a strip of soil that

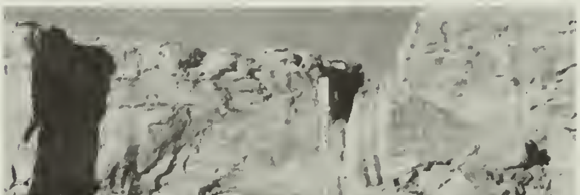


FIGURE 35. The wall depicted in figures 33 and 34 after pressure had been applied for three weeks by means of jacks in sleeves.

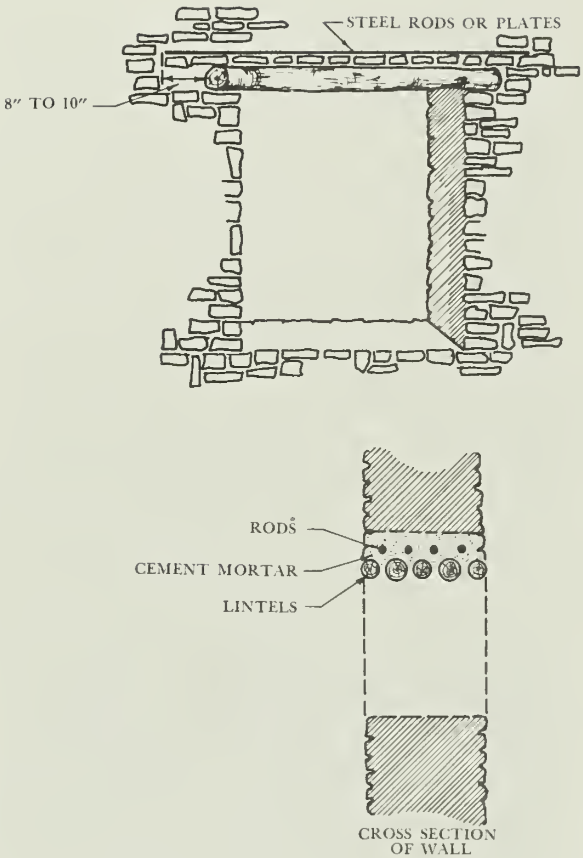


FIGURE 36. The placement of reinforcing in concrete mortar over pole lintels.

was the floor, or partly rotted vegetal material that was the ceiling, separating the two.

In repairing these strips, whatever remains of the ceiling material will have to be removed if it has not entirely rotted out (as is most likely). However, the location of the pole or savino sockets should always be preserved. The location of the sockets can usually be found while cleaning out the back part of the strip, or at least enough of them to indicate the location and spacing of the remainder.

The most satisfactory method of repairing pole or savino sockets is to cut several stub poles that are the same size as the originals. Oil them with a light motor oil. After the location of each socket is determined, set a stub in place of the original and make the patch around the stub. The stub need not be set in the wall the entire depth of the original, and the space behind the stub should be well filled with mortar. When the patch is completed and the mortar set, the stub can be removed. The hole is left in the exact shape of the stub and the stabilized mortar will hold the stone in place at the top of the hole.

The same method can be used in repairing large beam sockets, since they were seldom if ever finished off with a slab on the top, or made so that they would stand without the support of the viga. In rebuilding big viga sockets around a stub viga, it is usually best to use concrete and leave the stub in place some 24 hours to allow the concrete to gain an initial set.

Cast Concrete Members

Wood is the least durable material used in the repair of ruins. It may be treated with preservatives and protected from weight in the wall above by integral members which carry the load. However, large timbers are difficult to treat thoroughly unless facilities are present for complete immersion. Furthermore, the construction of integral members in small horizontal sections is time consuming. Integral members made in conjunction with the replacement of wood beams and lintels cause some disturbance to the adjoining

FIGURE 37. The cast concrete lintels have the same appearance as the originals from which they were cast. (Chettro Kettle Ruin, Chaco Canyon National Monument, N. M.)

masonry. The use of cast lintels and poles eliminates many of the above difficulties. They permit the replacement of wood with little disturbance; they provide a strong, rigid and very durable member. Cast lintels take the same surface and texture as the wood from which cast. With a little care they may be stained to faithfully reproduce the original (fig. 37).

Excellent instructions for making casts may be found in Chapter VII of the National Park Service publication entitled *Field Manual for Museums*. The data given below assume some familiarity with those instructions and with casting in general. They are given only as supplemental information, and apply only to the casting of concrete structural members in a three-part mold.

When several pole lintels are to be cast it is preferable to make a lumber form to hold the mold as long as the longest piece to be cast, and some 4 to 6 inches wider and deeper than the diameter of the largest piece. This form will hold the plaster mold around the original wood lintel, and will also hold this mold while the concrete piece is being cast. The form should either be hinged so that the sides swing away without interfering with the mold, or they may be fastened together with light bolts and wing nuts for ease of assembly.

In using plaster molds the piece to be cast must be dry and clean. Deep cracks and holes should be filled to within 1/8th inch of the surface with plasteline or similar material. The piece should then be well oiled with a light motor oil or one designed for use on concrete forms.

Close the lumber form and place 1 or 2 inches of fine damp sand in the bottom. Place the wood lintel on this sand and add more sand until the upper third of the pole is exposed. At this point provision must be made to key the parts of the mold together so they can be replaced in exact alignment after the pole is removed. Rounded depressions may be made in the sand and the plaster flowing into them will act as keys for the adjoining side of the mold. A more accurate method involves placing a bolt toward each end of the cast, thread down in the sand, and with the head protruding enough so that it will be set firmly in the plaster. This permits the parts of the mold to be bolted together and prevents movement in any direction. The bolts must be long enough to extend entirely through the sand.

Most field men are familiar with mixing plaster of paris and detailed instructions may be found in Chapter VII of the *Field Manual for Museums*. Enough plaster should be made for the first pour to cover the exposed part of the lintel and fill the wooden form to the top. Care should be taken not to entrap air bubbles in the plaster. When the pour is made, smooth off the top as the mold will be turned over and this part becomes the bottom on which the remainder of the cast will rest. If the mold is to be a large one such as for casting timbers or vigas, it is best to reinforce with strips of burlap dipped in plaster, with small dry branches, pieces of discarded reinforcing steel, etc.

After the plaster has set, pull back the sides of the form. Turn the form over gently and remove the sand. One-third of the pole will be set in plaster with the other two-thirds exposed. Shellac the edges of the plaster where the keys have been made. Oil this edge and the exposed part of the pole. Place the part just made with the pole attached in the bottom of the form (pole up) and reassemble the sides and ends. Place a strip of 2-inch lumber lengthwise on the center of the pole to separate the two remaining parts of the mold. Fill any inequalities between the strip and the pole with plasteline.

The second pour of plaster is made on both sides of the longitudinal strip, level with the top of the form, and completes the three parts of the mold. When the plaster has set, break the form and remove the three parts of the mold from the pole. Some care must be exercised in taking these various pieces apart.

When the parts of the mold are completely dry, shellac them thoroughly. Reassemble the parts back inside the wooden form, making sure that each fits correctly against the other. (There will be a 2-inch opening, lengthwise, between the pieces along the top.) Tighten the form so that there is no movement.

Oil the interior of the mold. Cut the correct length of reinforcing steel of 1 or 5/8ths-inch

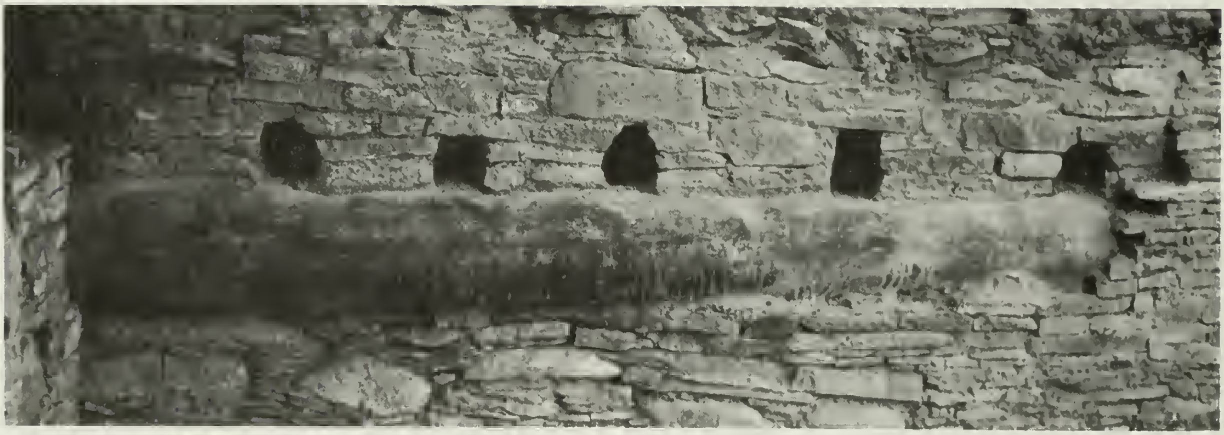


FIGURE 38. A horizontal cast log replaces the original timber which had rotted on the interior and in the embedded portions. (Chettro Kettle Ruin, Chaco Canyon National Monument, N.M.)

diameter. Mix a grout of sand and cement at 1-to-1 plus enough concrete with fine aggregate to fill the mold. The most difficult part of making a cast is placing the grout so that all inequalities in the surface of the mold will be filled, as this work must be done through the 2-inch opening. Coat the interior with the grout, place part of the concrete in the mold and embed the reinforcing in the center of the cast. Complete filling the mold with grout and cement.

There are various ways in which the cast poles may be colored. One of the most satisfactory techniques involves the following procedures. When the grout and concrete are prepared, a small amount of mortar color is added as a ground color. It must not make the mix darker than the lightest part of the wood lintel which is being copied. This serves as a base or background for the following stain. After the concrete is removed from the plaster mold, it should be cured in a warm, damp atmosphere for seven days and then let dry out slowly or it is apt to flake. After the curing period, scrub the concrete with zinc sulphate and let dry. It is now ready to stain. Ordinary penetrating wood stain (not varnish stain) is recommended by the Portland

FIGURE 39. Integral members. Starting a reinforced arch section, rods have been bent to fit the contours of the break and are wired in place. The workman is laying the courses across the bottom of the break in concrete mortar to provide a solid base for the reinforced section. Above this level, masonry on the perimeter of the hole will be laid in concrete mortar which will also surround the steel rods. Masonry in the center of the hole will be laid dry or with a minimum of soil mortar; its only function will be to support masonry laid in cement until the latter has set. This dry masonry will then be removed. (Pueblo Alto, Chaco Canyon National Monument, N. M.)

Cement Association. Start with a light stain and do not apply it evenly. Follow the directions for rubbing the stain off after a few minutes. Continue to stain the piece using darker colors until the desired effect is obtained.

The suggestions above have been given for making the mold of plaster of paris, a material fairly easy to work and one that sets rapidly. Experienced workers may wish to employ any of the various latex molding compounds if they are making large runs of one particular pole lintel.

Once the technique of simple casting has been mastered there is no end to the possibilities. Lintels may be cast with withes in place, duplicating the actual withes with which they were tied together in the wall. Particular logs which have been badly cracked or partially rotted may be cast in exact replica, and these placed back in position in the structure (fig. 38).

INTEGRAL STRUCTURAL MEMBERS

An integral structural member is an internal, reinforced concrete beam placed within the repaired portion of a structure to give added strength. It may be employed 1) in arch form to stabilize holes either part way or entirely through walls, 2) for both vertical and horizontal support, 3) to give added strength over horizontal timbers embedded in the wall, and 4) as bracing for overhanging sections.

Reinforced Arch Sections

With arch sections, large irregular holes may be stabilized "as is." The hole is still present and

FIGURE 40. Integral member; a large reinforced arch section. The size of the break through the wall precluded filling the center with dry masonry as support, and the timber framework was substituted. The heavily reinforced band is socketed in the cliff wall at the left side, and based on bedrock at the right. The integral member has just been finished and the mortar has not yet dried. After the mortar has set the timber framework, the dry masonry at the right and that on top of the horizontal plank were removed. The large hole with its original outline remained. (Gila Cliff Dwellings National Monument, N. M)

it has the same appearance and irregularity as before. When reinforced, it will be slightly smaller than the original, but will not develop further.

Full Width Sections

Almost any size or shape of hole can be stabilized by the following method, but little time or money is saved by using it for very small holes. To start a reinforced arch in a large break entirely through the wall, first clean the break to sound masonry and lay at least two courses in concrete mortar across the bottom of the break. More may be necessary in very large holes, or additional courses may be built up on the sides of the hole to form a good base on which to rest the steel which will follow.

Next, two pieces of light reinforcing steel 3/8ths or 1/2 inch thick are bent to fit within the outlines of the break. One piece goes on each side of the wall and just far enough inside the opening to allow a covering face of masonry. The two ends of each piece will rest on the masonry just laid across the bottom of the opening (fig. 39).

When the steel is in place, it should be securely wired and tied together with additional bracing where required. The purpose now is to build up a thin band or lining of masonry set in concrete mortar around the reinforcing steel. The repair masonry is laid in horizontal courses across the extent of the break, but only that part which encloses the steel reinforcing is laid in concrete mortar. The portion of each course which does not enclose the reinforcing is laid dry, but it must be laid solidly because it will have to support,

FIGURE 41. Integral members; steel in place for a narrow vertical section. The steel must be tied in securely to the cross wall at the top to provide support for the overhanging area. Some support will be required for the vertical strip of masonry as it is being laid, and until the concrete mortar has set. (Chettro Kettle Ruin, Chaco Canyon National Monument.)

FIGURE 42. Reinforced integral members are important in the stabilization of spirelike structures such as this at the Tower Kiva, Kin Ya-a Ruin, Chaco Canyon National Monument, N. M. Considerable strength must be added without serious or objectionable alterations of the original profile.

without shifting, the projecting stone in the vertical irregularities as well as all of the top of the patch until the concrete mortar is set. If the stone is very irregular, it is well to use some soil mortar in the center to give more stability. This procedure—concrete mortar between the stone on the outside next to the steel and dry masonry or soil mortar in the center—is followed until the top is reached. The top courses will also be set in concrete.

After the hole is filled, the concrete mortar area must be kept damp until the concrete has set. The dry masonry in the center is then removed and the hole is left in the same irregular shape (but slightly smaller) as originally, and protected from further breakdown by the reinforced band (fig. 40).

Exactly the same type of reinforced arch sections may be constructed in thick walls where only one side of the masonry is broken out. Ordinarily, only one piece of reinforcing is required.

Vertical and Horizontal Members

The principal application of these members is to tie together sections of separated and out-of-plumb walls, to reinforce walls against which there is pressure of retained fill, to re-lay overhanging and precarious sections, and to provide support over horizontal logs (figs. 41, 42, and 43). Since conditions and structures vary so greatly, it is difficult to anticipate all possible applications. In general, the requirements are:

1. Vertical sections must be based on adequate foundations, and the top should always be well tied into a stable part of the structure by means of longitudinal rods.

2. Care must be taken to achieve as good a bond or tie as possible between the member and the supported wall. Sufficient patching should be done adjacent to the member to prevent any separation from the wall.

3. In arch sections, in overhanging areas, and wherever steel will provide a major part of the support, care must be taken to adequately support the member by framework, dry masonry or the like until the concrete has gained full strength. Correct curing of the concrete in these thin bands is essential.

CAPPING

Capping is considered here as all repairs which extend to and include the tops of walls, and all work of resetting or otherwise altering the upper courses in masonry, brick or adobe construction to provide additional strength or protection against weathering. Capping is intended to tie the upper courses of masonry together, and may employ light reinforcement where walls are out-of-plumb or there are slight overhanging areas. Capping is intended to provide a water-resistant layer at the top of the wall, and to provide additional strength where walls are subjected to unguided visitor traffic.

In brick or adobe construction, primary reliance on the effectiveness of the cap must be placed upon the substitute masonry units used—stabilized adobes made for the purpose, new or treated brickwork. In setting cappings in stone masonry, strength and waterproofing will depend upon the substitute mortar employed. Standard construction practices require the use of continuous metal flashings in the upper courses of exposed walls tops, parapets, cornices and the like. This requirement can be met and the method employed where regular units laid in courses, brick and adobe walls, are being repaired. Standard architectural requirements should be studied and followed in this respect.

The use of metal flashings is impractical for sloping and random courses of masonry walls, particularly where there are great variations in elevation in a single wall. Here capping will be a compromise between sound, watertight construction, appearance and authenticity. Workers should investigate the possibilities of using fabric, plastic, or rubber flashing. Sheet lead might also prove workable.

Evaluation

The most durable capping on masonry structures of the Southwest, at least from the point of service, are some of the 1917-1918 cement caps made at Aztec by Earl Morris, and the 1920-1921 cement cappings laid at Chettro Kettle by Sam Huddelson for the School of American Research. Most soil-bitumen caps laid on various other Chaco ruins in the period from 1937 to 1940

FIGURE 43. The placement of reinforcing in the third story portion of the structure shown in figure 42. The purpose is to reinforce heavily the vertical capping which will be placed up exposed ends of the wall to prevent further erosion, and to tie this part of the wall together.

FIGURE 44. In many cases such as that depicted above it will be difficult to draw a distinction between general wall repairs and capping. This wall will have to be carried up to the level of the outside fill to prevent further washing over the top. Whatever type of mortar is used for such wall repairs, the top courses must be set in a cement mortar to provide as durable and waterproof a cap as possible. (Pueblo del Arroyo, Chaco Canyon National Monument, N.M.)

FIGURE 45. Patching of this hole at Pueblo del Arroyo will be combined with a short section of horizontal capping plus vertical capping for the exposed and weathered vertical rise of wall.

also are quite durable. These three capping projects employed the same technique, in that sufficient depth of stone was relaid in the mortar to provide some measure of tensile strength—an average depth of a foot or more. Each contained embedded stone laid in the same manner as the original work, and in about the same proportion of stone to mortar. Examination of these and other examples indicates that, to be successful, a capping must have sufficient strength and thickness to be a complete unit itself, and will be fastened to the top of the wall rather than a thin sheet or membrane laid over the wall to serve merely as waterproofing.

Field Control of Visitor Traffic

Over three million visitors toured National Park Service archeological and historical parks and monuments in the Southwest during 1972. The greater proportion of these visitors made unattended trips through the historic and prehistoric ruins. The day is past when ruins stabilization, particularly capping, is directed only to protection from the elements. Prime consideration must also be given areas receiving heavy use by the ever-increasing numbers of visitors.

Thus, for the capping of masonry walls, only the best cement mortar made with clean sharp concrete or mortar sand should be used. In many areas this graded sand must be trucked in from commercial sources. It is expensive, but it is also more economical than restabilization following a job using inferior materials.

At extremely isolated sites where materials must be transported long distances by pack animal, soil-cement made with local soils may be substituted for sand-cement mortar. However, it should be substituted only as a last resort since soil-cement, while resistant to weathering, does not usually produce a durable bond against foot traffic, the climbing up of protruding stone, and similar abuse.

1. In capping of any wall, sufficient loose and decayed material must be removed to insure a

good bond with sound masonry (of stone, brick or adobe) below (figs. 44 and 45). Where regular units are employed in coursed walls, a sound, even surface must be reached or built up on which to place the flashing. In most cases, sufficient courses should be removed to provide the desired depth of capping without the addition of new units. Where the upper levels of a patch are to form a cap, new stone or other units must be employed (fig. 46).

2. If possible, the work should be laid out so that each wall will be capped as a unit. It is not advisable to run capping across wall junctures. It makes for poor appearance; there is also apt to be some movement at this point, and if capping is carried across the juncture it will break at some weak area.

3. The capping of wide walls should be sloped or tilted to drain water away from wall junctures for a short distance, and laid so that moisture does not pond on the tops. Weak points of capping are at the outside bottom edges where the cap comes into contact with the wall face below. Capping should not be feathered out at these edges, but should retain their full cross-section. These are the points at which runoff enters the wall below, and every effort should be made to produce tight mortar joints with the underlying wall face.

FIGURE 46. A good deal of repair masonry must be laid to fill breaks and support undercut areas in this wall at Pueblo del Arroyo. Some support must also be provided for the embedded timbers. Soil or masonry cement mortars may be used for the major part of this work. The upper courses however must be laid in concrete mortar as capping to halt further washing from the top. In this example, damage was started by surface water from adjacent, unexcavated fill and every effort should be made to prevent erosion.

4. Any capping will be a comparatively thin and weak part of the structure. Every effort must be made to produce a durable job. All stone employed should be clean and free of soil. It should be damp when placed in the mortar to insure good bond, and to prevent too rapid drying of the mortar. Control must be maintained over the mixing to prevent excessive amounts of sand or water. Lastly, some provision must be made to insure proper damp curing.

5. Treatment of capping with silicone waterproofing is recommended, particularly those caps employing adobes or stabilized adobes and similar units.

CONTROL OF EFFLORESCENCE

Efflorescence, the appearance of whitish "alkali" deposits on wall surfaces, is a problem closely related to several others covered to this point, including the use of cement mortars, the rise of capillary moisture in walls, and the repair and capping of these walls. It is a condition which is occurring with increasing frequency in the Southwest, particularly in stone masonry structures.

In brief, efflorescence is the result of water soluble salts in masonry brought in a water solution to the surface. The salts remain following evaporation of the water. Two conditions are required before efflorescence will occur: 1) water soluble salts present in the newer masonry components, or in the older components onto which the new work has been added; and 2) presence of moisture to dissolve and carry the salts to the surface. The moisture may be hygroscopic, capillary, or hydraulic in nature. The soluble salts

which cause efflorescence may be present in varying amounts in sand, cement, lime, admixtures, mixing water, and masonry units, both new and old.

The primary steps one must take to control efflorescence include the careful selection and use of materials, and the employment of workmanship and design practices which prevent the entrance of water into masonry work. Stone, water, and sand in the vicinity of some sites undergoing stabilization are highly suspect with regard to the presence of deleterious salts. As mentioned earlier in this chapter under "Repair of Wall Breaks," time can be saved if suitable rock and spalls are quarried. The sand should be washed. The mixing water for masonry mortar must be clean and should be pure enough to drink. The following practices will aid in the elimination of efflorescence: 1) in all sizable masonry work that is one stone deep or more, fill head and bed joints completely with mortar; where walls are more than one stone wide, fill compound wall core with rubble and spalls completely embedded in mortar; 2) design capping deep enough to shed water, laying cap stones in such manner that they cannot trap water; 3) cover the top of completed masonry work to keep out rain; and 4) where fill lies behind the wall, seal the back side as described under section entitled "Control of Capillary Moisture."

Where salt deposits have become highly objectionable, attempts should be made to curb the source of moisture, by brushing, and with the use of solvents. A light sand blasting should be made only as a last resort, followed by treatment with a hydrocarbon-based silicone (Daracone or equal).

ROOFING AND ROOF SUPPORTS

In the past, a variety of methods have been used for protecting existing prehistoric ceilings and roofs *in situ*. They range from the elaborate evaporation-pan type roof installed at Aztec Ruins in the early 1920's to simple, temporary structures. Due to the very nature of the problem —intact ceilings often a story or two below the upper limits of the walls—protective coverings have been difficult to construct, and few have been unqualified successes. Protective coverings of a permanent nature have seldom been constructed near the tops of walls, a story or more above the ceilings, for the following reasons: 1) the difficulties of roofing irregular wall tops, 2) the unsightly appearance of roofs protruding above the masonry, 3) the openings between the ceiling level and the wall top which must be closed or sealed off, and 4) the aboriginal ceilings which often require some support from the protective covering.

Despite their imperfection, the early evaporation-pan roofs installed at Aztec were soundly designed and constructed. They were of concrete slab construction, made to hold water until it evaporated. Such a design obviates the need for drainage lines and downspouts and does not mar the appearance of a site. The roofs functioned quite well during the summer and fall rains; they had ample capacity for seasonal rainfall. During the winters, however, they accumulated great depths of melting snow and ice, and the water level rose above the limits of the pan. At this level, water worked through the masonry and entered the ceiling material below. In time,

FIGURE 47. Temporary support of cracked and broken roof beams by means of jacks and timber props. Approximately 6 feet of overburden lay on this ceiling. The temporary supports were in place for several years before the overburden could be removed and a protective roofing constructed. (East Ruin, Aztec Ruins National Monument, N.M.)

FIGURE 48. The ceiling shown in figure 47 after removal of the overburden and construction of a slab roof which protected the ceiling and permitted support of broken beams. The bolts are fastened in the slab above, and were taken up enough to transfer most of the weight from the old ceiling beams to the new roof.

the concrete of the pans subjected to constant moisture and alternate freezing and thawing began to crack and the surface to disintegrate.

As a remedy, the evaporation pans were remodeled into roofs with drains. Hidden tile drains were installed in the heavy walls and the concrete slab was covered with a built-up type roof covering, finished off with pea gravel or chips. This solution has been only partly successful because the drains frequently became clogged. Most drains are situated at the north side of the site and became stopped with alternately freezing and thawing snow and ice during the winter months. Some of the more troublesome drains were later converted to larger size, opening directly to the exterior of the wall. The result is less attractive, but provides a watertight roofing.

From this and similar experience with difficult roofs evolved the coverings designed for and installed over 14 prehistoric ceilings in the East Ruin of Aztec during 1957 (figs. 47 and 48). These were in an unexcavated site where the only previous protective measure taken was the temporary bracing of cracked and broken timbers.

Requirements and dimensions for a protective covering will vary from room to room. However, the major limiting factor is the strength and condition of the walls which support the new roof. In many instances, such as the heavy-walled construction of Pueblo III, stabilized walls are sufficiently strong to support a permanent slab-type roof. Where the weight is excessive for existing walls, the same type of slab roof can be constructed, supported by upright members, i.e., steel I-beam supports rising alongside the walls and based on concrete slabs at floor level. The vertical columns will support the slab while lateral stability is provided by the walls. The vertical supports must pierce the aboriginal ceiling and they must do so at points where they do not interfere with its important members, but where they also furnish the required support.

Slab Roofing

Since ceiling areas vary considerably in size and span, and the condition of the walls also varies, the following are general suggestions only on the construction of concrete slab-type coverings for protection and support.

Lightweight concrete made with commercial lightweight aggregates has extensive use in the construction of modern roof decks. Every consideration should be given to its use when designing slab-type coverings. Weights of concrete made with lightweight aggregate run from 25 to 50 pounds per cubic foot as opposed to an average of 150 pounds per cubic foot for concrete made with sand and crushed rock aggregate. This permits coverings where the weight of heavier aggregates would be prohibitive, and also permits the use of much lighter members below the slab. When sand is added to the lightweight aggregate, a medium weight concrete results; a wide range of strengths may be obtained by varying the proportion of sand to lightweight aggregate. In general, lightweight slab construction should be based on corrugated metal such as Corruform or Tufcor rather than upon paper-backed metal lath or ribbed metal lath. The thickness of ordinary lightweight concrete decks varies from 1 1/2 to 3 inches.

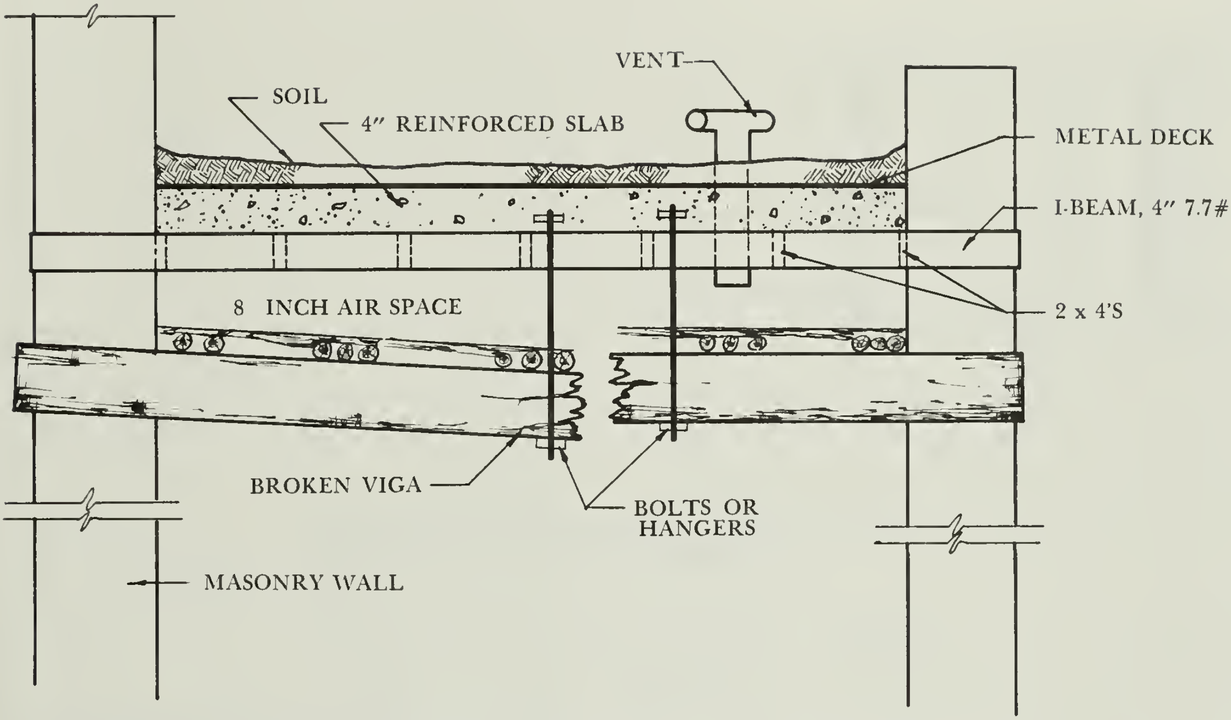


FIGURE 49. Typical roof covering and support employed at Aztec Ruins National Monument.

The general design of slab-type roofings are shown in figures 49, 50, and 51. No part of the new roofing may be supported by the aboriginal ceiling either during or after construction. This requires that the construction be self-supporting during the time that the concrete is being poured. Ordinarily, concrete forms for floors and decks are supported during pouring by vertical members from below, and the supports and forms are removed after the concrete has set. However, this is not possible in the placement of slabs over existing roofs where the space between the new slab and the old ceiling is usually less than a foot, and there is no means of access between the two.

The basic members of the new roofing should be steel I-beams. Their construction permits the wood members of the roofing, the rafters or purlins, to be inset in the sides of the beams. Thus, there is no wood separating the concrete from the main supporting members. Wood left in this position would rot and allow the roof to settle. Dimensions of the I-beams are determined by the span, the placement of beams and the type of slab, and the normal or lightweight concrete used. Roofs with a span of 6 to 8 feet normally require 4-inch beams of 7.7 weight, on 4-foot centers. The I-beams should be run through the full width of the wall and should rest on a concrete pad if possible.

Likewise, the number and placement of the wood members of the roofing is determined by the type and thickness of the slab to be poured. They should be ample to support the wet concrete and be well nailed and braced.

While paperbacked metal lath can be used under lightweight concrete, it is preferable to use one of the standard corrugated metal deckings as a covering for the structural members and a base for the concrete; it is light in weight, and easy to handle and cut.

Whatever concrete is used should contain reinforcing, the amounts depending somewhat upon size and weight of the sections of the ceiling below. For example, in the roofs with beams on 4-foot centers, No. 4 rebar was placed on 8-inch centers at right angles to the I-beams. Number 3

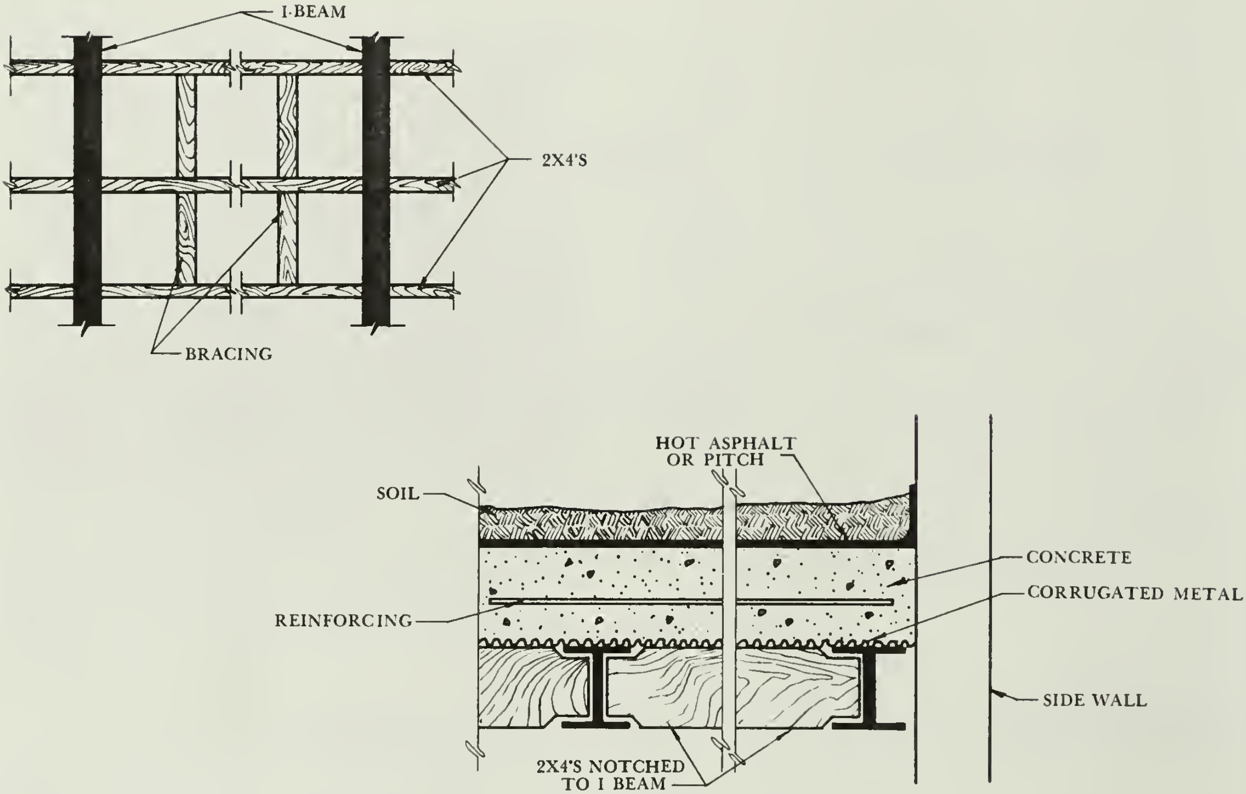


FIGURE 50. Details of roof supports (in section) at Aztec Ruins National Monument.

rebar was used at right angles again, the short dimension of the slab, on 18-inch centers. Concrete slabs will usually be about 3 inches thick and the reinforcing should be above the center, supported on "chairs" of steel or similar material. All reinforcing should be securely tied. It is preferable to purchase the reinforcing cut to length and the ends bent if desired.

Ceiling Supports

If the prehistoric ceiling has been subjected to heavy overburden or has been wet, it will probably require support from the protective slab, a provision which must be made when the slab is first being laid out. Support may consist of bolts which extend up through the center of broken or cracked beams or by pairs of bolts, one on each side of the beam to support a hanger under the beam. Bolts should have ample threads (threaded rod is preferable to standard bolts) so that they can be taken up sufficiently to support most of the weight on the beam. In normal concrete, large cut washers are sufficient to anchor the bolts; in lightweight concrete the upper ends of the bolts or rods should be tied in to the reinforcing. Ventilation must be provided between the old ceiling and the new roof to prevent accumulation of excessive moisture from condensation. Most prehistoric ceilings are not tight enough to prevent some movement of air. When clearing debris or covering preparatory to constructing a slab, sufficient material should be removed to permit some percolation of air through the ceiling. Provision should also be made for ventilation through the top. This is best accomplished by including a vent of 4-inch pipe in the slab, the ends covered with screen or turned down.

Finishing and Flashing

One of the most troublesome problems encountered in the construction and maintenance

of roofs set deeply within structures is that of flashing. It is impossible to place metal flashing in the usual irregular ashlar of a ruin wall without tearing out a wide band of the masonry and relaying it with the flashing in place—a dangerous procedure in deep rooms, impossible in narrow walls and always weakening to the structure.

To avoid the difficulties of inserting metal flashing, well-formed cant strips should be employed. They do not always provide the absolute freedom from water seepage as a correctly employed metal flashing, but they are often the only possible alternative. In placing cant strips, either in new roofs or in repairing existing slab roofs, the wall where the strip is to lay should always be cleaned and the joints well pointed with cement mortar some distance above the top of the strip. This strip can then be waterproofed with hot asphalt, pitch or whatever material is used on the remainder of the roof.

FIGURE 51. Construction of a slab covering. The numbered members are I-beams run through heavy masonry walls. The longitudinal members are 2 x 4's inset in the I-beams as purlins. Corrugated metal decking will be nailed to the wood as a base for a concrete slab. A covered vent will be provided through the concrete. Drainage will be provided by tile line through the wall at the right. (East Ruin, Aztec Ruins National Monument, N.M.)

In pouring the slab, every effort should be made to produce as dense and watertight concrete as is possible. The water-cement ratio of normal concrete should be strictly controlled. When poured, the material should be well-rodded and the top screeded, i.e., leveled out to grade to a true, even surface. Whether of normal or lightweight type, it must be damp cured for no less than three days and in hot weather protected from excessive drying for a longer period.

The use of either type of concrete will require a waterproofing surface. Either kind must be thoroughly dry before the surface is applied. Lightweight concrete should be covered with a built-up roof, surfaced with chips or pea gravel. While normal concrete is employed, it also must be waterproofed. A built-up roof can also be used.

Where it is desirable to cover the slab with soil for improved appearance, the slab may be waterproofed by an application of hot pitch mopped on. Pitch does not deteriorate as rapidly under a soil covering as the usual asphalts used for built-up roofings. If a soil covering is to be used, the wall surface should be repointed with concrete to at least the depth of the soil, and this area also waterproofed by an application of pitch.

SETTLEMENT AND SUBGRADE

As mentioned in this book, one of the common structural faults encountered in prehistoric sites involves the loose and unconsolidated fill upon which they were built. True foundations or footings are not present in prehistoric sites. Walls were usually laid on existing ground surfaces with some attempts at leveling and occasional terracing on sloped areas. In some cases a trench was prepared for the first several courses of masonry. Inadequate foundation conditions include walls or parts of walls which rest on materials containing organic matter, on low density materials such as loose deposits of silt or sand, and on talus deposits, spoil piles, and dumps.

By contrast, the post-1540 A.D. historical structures of stone masonry or adobe bricks were built on true, prepared foundations. Unless they were located on favorably drained loca-

tions, however, many were not waterproof because the foundation stones were laid either in soil mortar or porous lime mortar.

It is surprising that wall failures resulting from settlement are not more common. In the Pueblo III multi-storied structures of massive masonry, vertical cracks and slumped or severely leaning segments are frequently noted. These are the result of stresses and bearing loads of heavier walls. Shear stresses from unequal settlement are often indicated by cracked or broken masonry stones.

In modern construction of foundations, a careful evaluation of the subgrade soil is necessary, requiring tests which serve to define the character of the material and the quantitative properties which define specific performance characteristics such as shear strength, pore-water strength, capillary stress, compressibility, and permeability. Foundations for rigid structures are usually evaluated on the basis of bearing capacity which involves both the shearing strength of the soil and its consolidating characteristics. Therefore, the conditions for which adequacy of a foundation should be established include bearing capacity, stability, settlement, and permeability. Field and laboratory tests required to measure these characteristics demand specialized equipment and highly experienced investigators.

Soils containing large amounts of silt and clay are rather unstable. These materials exhibit marked changes in physical properties with change of water content. A hard, dry clay may be suitable as a foundation for heavy loads, but may turn into a quagmire when wet. Many of the fine soils shrink on drying and expand on wetting which may adversely affect structures founded on them.

A frequent occurrence in valley fills of the Southwestern United States is the percolation of water through soils. This results in the gradual removal of soil particles either by solution or mechanical movement of particles, introducing disturbances in the overburden indicated by piping and sinkholes. Where such pipes and sinkholes are sufficiently close to prehistoric or historic sites to threaten stability of the structures, they should be stripped to sufficient depths and filled with impervious compacted soil.

The fine grained valley fill-soils in the populous archeological areas such as Chaco Canyon contained sufficient gradation, uniformity, and in-place density of silts, clays, and sands at the time the large sites were constructed to provide a proper amount of compactability and compressibility for bearing the weighty architectural loads. Exceptions, of course, resulted in the occasional slumped and leaning walls involving massive masonry. Today in Chaco Canyon some of the ruin areas are covered with several feet of aeolian silt and sand which are unsuitable for foundation material. Piping and sinkholes in the valley floor near the central arroyo pose threats both to modern and prehistoric construction.

UNDERPINNING AND SHORING

The most frequently used and simplest method of improving foundation stability and halting settlement is to excavate beneath the lower limits of the wall, remove unsuitable material, and spread the base by installing a widened footing of masonry so that unit pressures are acceptable. If large wall areas are involved, short sections of underpinning must be installed and allowed to cure before moving to the adjacent section, thereby not leaving too much wall unsupported at one time.

Concrete piers or foundations may be installed by the above skip-tunnel method. Both horizontally and vertically placed reinforcing rods should be installed before the concrete is poured. Any shrinkage between a cured foundation and the wall it supports must be tightly grouted before trenches are backfilled, tamped, and the surface soil graded to drain away from the wall and concealed footing.

In modern construction it should be realized that, unless a structure rests on solid rock foundation, some settlement cannot be avoided. Where it is not feasible to found a structure on solid rock either by placing it directly on bedrock or by means of poles, piers, caissons or walls, the structure must be capable of withstanding some vertical movement in the foundation. As

suggested for underpinning prehistoric structures, the usual method of reducing movement along the foundation to within acceptable limits is by spreading the base or footings so that unit pressures are sufficiently small.

Wherever historic and prehistoric structural foundations have been investigated, it has been shown that a firm, uniform foundation soil, free from loose sand, low density silt, soft clay, isolated rock masses, or cultural refuse, proved adequate for most structures with moderate loadings.

SUB-SOIL INTRUSION GROUT

While a broad guide to the character and gradation of soils can be accomplished by personnel with little training, the determination of soil engineering properties requires considerable skill and insight if reliable information is to be developed. Therefore, in complex problems involving cause of foundation failures, and for providing engineering-designed remedial measures for settlement of walls, it is suggested that the field man call upon the services of a soils and foundation expert. Moreover, foundation problems in general are not susceptible to exact engineering analysis, even with careful soil sampling.

A valuable illustration of how a serious foundation problem was solved at Canyon de Chelly National Monument by the National Park Service, in cooperation with a large, private firm skilled in soil stabilization, concrete, and cement grouting, is briefly outlined below. The solutions have wide application to historic structures elsewhere, particularly those which may be severely cracked due to settlement of foundations.

White House Ruin, a four-story stone masonry pueblo dating from ca. 1050-1300 A. D. was built on valley fill against a sheer canyon wall of a stream which flows part of the year. The water table fluctuates seasonally, but is always consistently high. The present sandy stream bed is 50 yards in front of the ruin. During the dry season, water can be reached at from 3 to 4 feet below the surface sand. Before prehistoric occupation of the canyon, the stream channel flowed at various times along and at the base of the cliff. Lat-

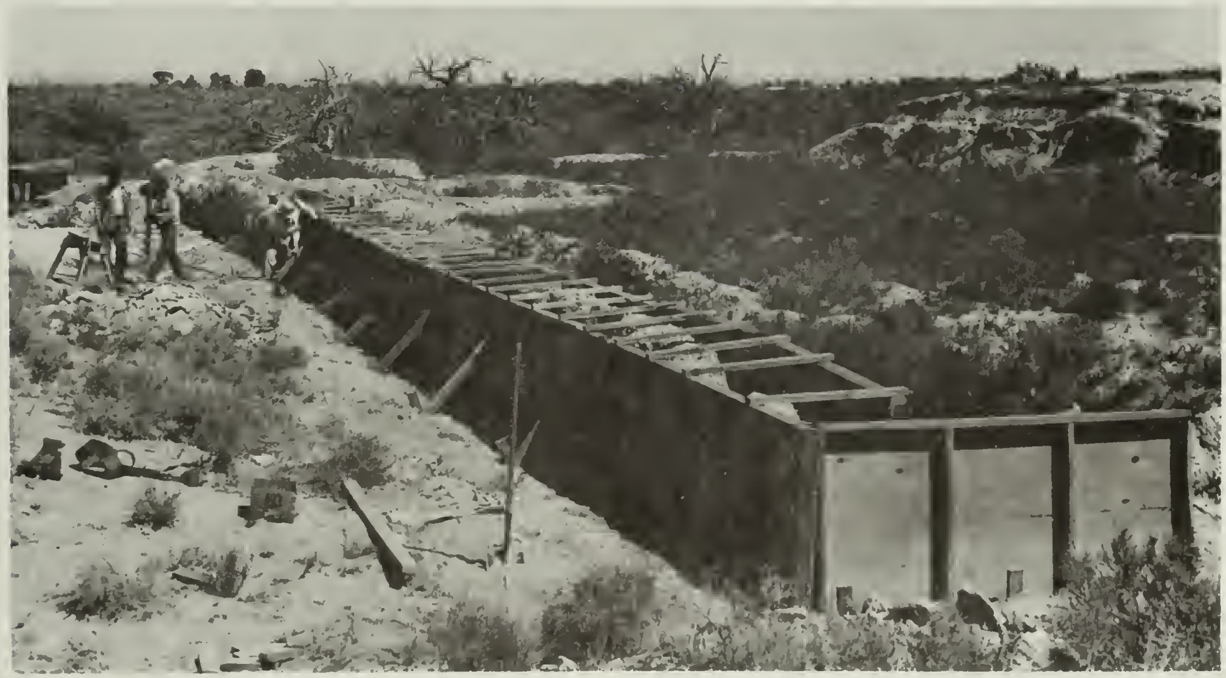


FIGURE 52. Placement of forms for stabilization of a wall with caliche-based soil cement. The forms are braced at the sides and tied at the top. (Compound B, Casa Grande Ruins National Monument, Ariz.)

er, sediments and alluvial fill built up against the cliff and it was along these strips of fill that the prehistoric Indians built their homes. Stabilization of the ruin was accomplished in 1941-42 and again in 1956 by the National Park Service. Work was confined to minor repairing and patching of walls which suffered defects partly from weathering, but increasingly more from visitor impact. By 1958, however, large vertical and diagonal cracks, as well as wall separations, were rapidly developing throughout the structure.

A thorough inspection of the site was made by National Park Service archeologists and the chief engineer of a large private firm whose speciality is foundations. In the opinion of the engineer, seasonal fluctuations in the water table were removing fines from the upper soil strata. This downward migration of fines is very common in valley configurations and results in reduced density and bearing value of soil immediately beneath structures founded on the valley floor. The engineer suggested that it is usually possible to improve these values by intrusion-grout injection. The problem was further complicated by the fact that some walls of the ruin rest on refuse and earlier occupation debris.

In the best judgement of the assembled experts, two courses of action were considered for attempting to save White House Ruin:

1. The most positive method, and by far the most expensive, involved the use of concrete cast-in-place or mixed-in-place piles placed adjacent to the failing foundation or lowest limit of the wall and tied to it by means of needle beams beneath the wall. To be effective, the entire length of the wall must be supported by a grade or bearing beam which, in this case, would have to be installed by tedious hand methods. Because of the expense involved and the considerable disturbance of underlying occupational debris, pile underpinning was ruled out: National Park Service budgets simply could not bear the cost.

2. The second method of foundation improvement consists of injecting intrusion grout into the unstable soil. This relatively economical process, described below, depends very largely for its success on the skill and experience of the job superintendent and the reliability of the firm. It is a technique which has been applied in literally hundreds of commercial situations with complete success in most cases.

The second method was chosen for White House Ruin and was successfully performed in October 1958. Since that date, no further settlement of walls has been detected. In a subsequent stabilization job, undertaken shortly after the substrate was consolidated by grouting, all cracks and defects in the superstructure were corrected not only to make the ruin stable again, but also to allow us to observe any further settlement should it occur.

The intrusion process of sub-soil stabilization is accomplished by placing small diameter pipes up to 30 feet in length into the soil to be stabilized. Intrusion grout is forced through these pipes to fill voids and to consolidate the material. By repeating this process the required number of times, the soil is strengthened by the material placed and a raise can be effected by the hydraulic pressure exerted while placing the intrusion into the soil. The lateral distance between inserted pipes and the amount of stabilization required varies with soil conditions and loading specifications.

The intrusion grout used at White House Ruin was a cement base slurry which included the patented admixtures, Intrusion Aid and Alfesil. Intrusion Aid provides delayed setting, suspension of solids, low water-cement ratio and compensates for normal setting shrinkage. Alfesil is a premium grade of finely divided siliceous material which contributes to the penetrability of the grout. Alfesil is pozzolanic material composed essentially of compounds of silica, aluminum, and iron. It possesses the property of combining with lime that is liberated during the process of hydration of portland cement to form additional insoluble cementitious and strength producing compounds.

Exceptional care was exercised during grouting operations since hydraulic rise was to be avoided. The grout pipes were driven into the underlying material adjacent to and under the walls throughout the ruin to a depth of 20 feet.

Grade stakes were established adjacent to the walls at strategic points, and a careful check maintained to avoid all but the faintest movement of substructural material. The grout was pumped into the soil under controlled pressure as the grout pipes were slowly withdrawn, creating lenses and columns of hardened grout within the foundation material to increase its bearing capacity.

It is emphasized that sub-soil intrusion grouting beneath irreplaceable ruins is not a do-it-yourself project. Every foundation presents a distinct grouting problem, depending on the composition and nature of the substrate. The method requires considerable specialized, highly mobile equipment permitting economical placement in normally inaccessible locations. Equipment includes an air compressor, paving breaker and driver head, air-operated grout mixer, water batches, and grout pumps, together with insert pipes, grout, air and water hoses, level, gauges, fittings and various hand tools. The job superintendent, crew chief, and laborers must be highly skilled and experienced.

Tests were conducted throughout the White House Ruin project to obtain reliable information on the increase in soil density as result of grouting, at the same time permitting no hydraulic rise which, if not gauged properly, would have lifted walls out of the ground. Since 1958, the sub-soil stabilization at White House Ruin has halted the settlement of the substrate and the subsequent cracking, separating, and shearing of prehistoric masonry.

MONOLITHIC STRUCTURES

The history of the preservation of monolithic soil structures such as occur at Casa Grande, detailed elsewhere in this book, has been one of experimentation, frustration and unsatisfactory results. The early use of burned brick in repairing and supporting large undercut sections of the "Big House" in Compound A has proven eminently satisfactory. Much less satisfactory have been the preservation attempts on low and exposed walls in the remainder of Compound A, Compound B, and the Clan House. While waterproofing and hardening solutions have been tried, the major effort directed toward preservation has been with thin coatings or plasters of soil-cement, soil-cement made with caliche, cement stuccos, and a covering or capping of formed adobes. Caliche is a crusted calcium carbonate formed on certain soils in dry regions.

None of these have proven to be the ultimate, one-application panacea. All the various coatings or plasters have had to be renewed. However, it should be pointed out that they were not all complete failures. Although they must be replaced, these coatings have protected and saved many prehistoric walls. The earliest of the coverings were of thin cement stucco; they were followed by the use of soil-cement at a fairly stiff consistency, and tinted to match the original work. They were plastered over all exposed surfaces. The weakness of these applications, soil-cements and cement stuccos, was the absolute lack of bond between the prehistoric wall and the "plaster" as well as the tendency of the plaster to absorb moisture and thus aggravate the lack of bond. The appearance of such surface coverings was undesirable.

The addition of woven wire and other reinforcing material in the plaster has lengthened the life of some of these surface applications of soil-cement. Recently developed water repellents applied to the surface indicate that they also will materially prolong the useful life of the repair.

Since long experience at Casa Grande has demonstrated that it is impossible to make a thin covering of either cement, stucco, or soil-cement which will adhere to the original wall or will not crack and remain waterproof, a slightly different approach has been tried recently on exposed walls of Compound B.

The thought behind this approach is that a heavier, thicker section of soil-cement or caliche-cement would not be dependent upon the prehistoric wall for bond and support but would, if thick enough, be self-supporting. Given the present state of knowledge, it is evident that we will not be able to develop and thoroughly test any preservative or hardening solution for exposed soil walls in sufficient time to abandon

FIGURE 53. The start of placing caliche-cement mix over the wall depicted in figure 52. Note that the forms follow the irregular line of the wall.

other tried, though partial, solutions. It is for this reason that formed soil-cement or caliche-cement coatings have been used recently at Casa Grande. With modifications, they may be used in other, similar situations. They represent the latest step in the evolution of plaster-like coverings, and it is possible that they may prove to be the final solution.

Formed repairs to badly weathered walls of caliche at Casa Grande (exposed since the excavation was completed in 1908) are more natural appearing than are the thinner, plastered coverings. The thinner coverings followed the undulating, irregular, undercut convolutions of the wall. The former repairs are somewhat more regular and more nearly match the formed appearance of the original wall surface.

Following is a brief description of the latest wall surfacing work at Casa Grande.

In all caliche walls, i.e., those of high lime soil content encountered in Compound B, weathering had greatly reduced the original width above the surface of the ground. Both sides of the wall were trenched until the original width was reached at depths up to 18 inches. Forms of heavy plywood, reinforced with 2x4's, were then placed at the edge of the wall rising vertically from the uneroded subsurface line (fig. 52). The space between the remaining wall surface and the forms was wide enough so that the caliche-cement would be sufficiently thick to stand by itself, and not be dependent on the aboriginal wall for support. General requirements for placing concrete forms were followed: they were oiled, and securely braced.

Trial mixes of several local soils were made. A caliche obtained from commercial sources was selected for use as most nearly matching the pre-

historic wall and providing the hardest product. A mix of 18 percent cement with a small amount of mortar color was used. A portable, drum-type mixer was used.

The prehistoric wall was dampened and the mix placed between it and the form (fig. 53) well tamped in place to fill undercut spots. It was placed at a depth sufficient to cover the rise of the wall face and was then sloped to conform to the irregular, sloping surface of the wall top. After curing, the forms were removed and when completely dry the entire surface was treated with silicone water repellent (fig. 54). This use of heavier, self-supporting coverings of native materials parallels the already proven use of heavy sections of soil-cement in the repair of pit houses and for making facings in cuts in soft fill (figs. 9 and 10).

ADOBE STRUCTURES

This subject is closely related to monolithic soil structures in that the raw materials are the same. Only the method of construction differs. The word "adobe" appears to have come from the Spanish, *adobar*, to plaster, traceable through Arabic to Egyptian hieroglyphic for "brick." Hence the term has come to mean "sun dried brick." Adobe is, therefore, merely soil or earth—usually a combination of sand, clay, and silt mixed with water used in the manufacture of a brick in a mold. Bricks made from soil in this manner are also called "adobes." The best adobe soil is a coarse grained, well-graded earth (see Chapter 3). It is not to be confused with the so-called adobe clay or gumbo found in some strata which heaves and expands when wet, and shrinks badly when drying, forming large cracks (Neubauer, n. d.). This material is identical to the soil or earth mortar employed by the prehistoric Indians in laying stone masonry, in pit house construction, and in the *pisé de terre* construction of Casa Grande where the puddled or stiff mud was laid in thick courses.

FIGURE 54. The application of a silicone water repellent. It is applied in a coarse stream, sufficient to produce a rundown of from 6 to 8 inches. (Casa Grande Ruins National Monument, Ariz.)

Other writers have shown that adobe or earth brick construction has a long history, going back to B. C. 7000 in the Near East; to B. C. 5000 in Anatolia, Crete, Egypt, and Indus Valley; and to B. C. 3000 in the Chicama Valley of Peru in the New World (Lumpkins, 1971; Steen, 1971). While adobe construction was known in Peru and Mexico before the arrival of the Spaniards in the 1500's, nevertheless it is they who are generally credited with having introduced the form-molded earth brick to the Southwestern United States.

Soil has very little strength compared to other materials used for building a structure. Moreover, compared to the maximum soil strength that may be found, there is a great variation both from soil to soil and within a given soil type depending on how it was deposited or placed. Since moisture is the most influential factor affecting the properties of a soil, and is the principal agent subject to change from natural causes, it is not surprising that adobe construction is confined largely to arid and semi-arid regions of the world. In the United States, adobe construction is found principally in the Southwest and West in areas of low rainfall, where average annual precipitation is 20 inches or less.

Recognizing the severe limitation of adobe construction, its successful longevity depends,

FIGURE 55. One of four 2-story adobe structures, designated HB-14, at Fort Davis National Historic Site. The building was probably used as a residence for important non-commissioned officers. Front view in 1964 before repairs were undertaken by the National Park Service.

FIGURE 56. Stabilization and modified restoration in process at HB-14, shown in figure 55. Soil-cement adobes were used for repairing walls. A concealed integral bond beam was installed around the building between the first and second story levels. Concrete bearing beams were installed at roof line to support restored roof.

FIGURE 57. The completed stabilization and modified restoration of building HB-14, Fort Davis National Historic Site. Compare with figures 55 and 56.

FIGURE 58. Building HB-15, a non-commissioned officers quarters at Fort Davis National Historic Site, before combined stabilization and modified restoration work was accomplished by the National Park Service.

FIGURE 59. Building HB-15 and its outbuilding, a kitchen, following modified restoration by the National Park Service. Soil-cement adobes simulating original adobes were used as modular units of repair. Compare with figure 58.

as one writer so colorfully put it, on three things: an adobe building should be given a pair of rubbers, a hat, and sometimes a raincoat (Hubbel, 1943, p. 23). Thus to preserve and maintain an adobe structure successfully, it must be well drained and the foundation must be waterproof to prevent the entrance of either hydraulic or capillary moisture. The structure must be properly roofed, and the exterior walls should be waterproofed either with a material mixed with the bricks or protected by a plaster or stucco surface. If any of the three essential protective elements are missing, the structure is vulnerable to deterioration which may range from extremely rapid (virtually overnight in the event of a cloudburst) to very slow. The two most important elements are roofing and foundation. If both are sound and waterproof, an adobe structure will last indefinitely, and the rate of erosion of the exterior walls will be greatly minimized.

Upon acquisition by the National Park Service of such historic sites as Fort Bowie, Fort Davis, Fort Union, Pecos, Tumacacori, and the early 20th century Spanish-American residences in Big Bend National Park, nearly all of the adobe structures were in ruins. Walls were standing to their original height only in those rare instances where a building was maintained until (or a few years prior to) the date of acquisition by the National Park Service. All of the structures at Fort Bowie, Fort Union, and Pecos were in ruinous condition. Many were reduced either to low mounds or mere foundations.

It should be mentioned that by 1900 the roof of the nave at Tumacacori was missing, the result of a combination of vandalism and erosion. The sidewalls, which were constructed of adobe bricks, had begun to deteriorate very severely. If Frank Pinkley, then "The Boss" of the Southwestern National Monuments Organization, had not installed a roof over the nave and performed other repairs in 1920, there would be very little left of this 18th and 19th century mission other than a mound of "melted" adobe.

Modified Restorations

In view of the above comments, the most effective method of preserving an adobe building involves a partial or modified restoration, especially applicable where sufficient architectural remains are present, and assuming that adequate documentary and archeo-historical data are available. Figures 55 through 59 show modified restorations at Fort Davis National Historic Site where it was possible to reconstruct walls partially to the extent necessary to support new roofs and to arrest deterioration. Authentic roofs and porches were constructed, based on good evidence. House interiors were left largely as found. This treatment accomplished the dual purpose of preserving the original fabric of the structures and creating an effect, so far as external appearances are concerned, similar to the historic period.

This construction restored the exteriors of two 2-story buildings to their original appearance. The tops of the walls, weakened by erosion, were rebuilt and capped with reinforced concrete-bearing beams to support new roofs. Where exterior faces of adobe walls were severely weathered, a masonry veneer was added to rebuild the wall section to its original thickness using soil-cement units colored and textured to match the existing adobes. New wood porches were added to the exterior entrances, and doors and windows restored to the openings to secure the buildings. Thus the structures are interpreted as part of the historic scene. A self-guiding trail provides access and supplies necessary for interpretation.

The visitor center at Fort Davis is an adaptive restoration. The 1870 enlisted men's barracks, which was a roofless, ruinous shell in 1964, was left virtually intact and a modern veneer of soil-cement bricks built around it. Some sections of original adobe walls were pared down so that the veneer would make up the original width. Bearing beams and integral support were provided for the modern though authentic roof. The restored portion of the exterior was faithfully preserved in both form and detail, while the interior was converted to modern, functional use (figs. 60 and 61). A small, glass-enclosed framework on the interior of the restored barracks shows an original portion of adobe wall for viewing by visitors.

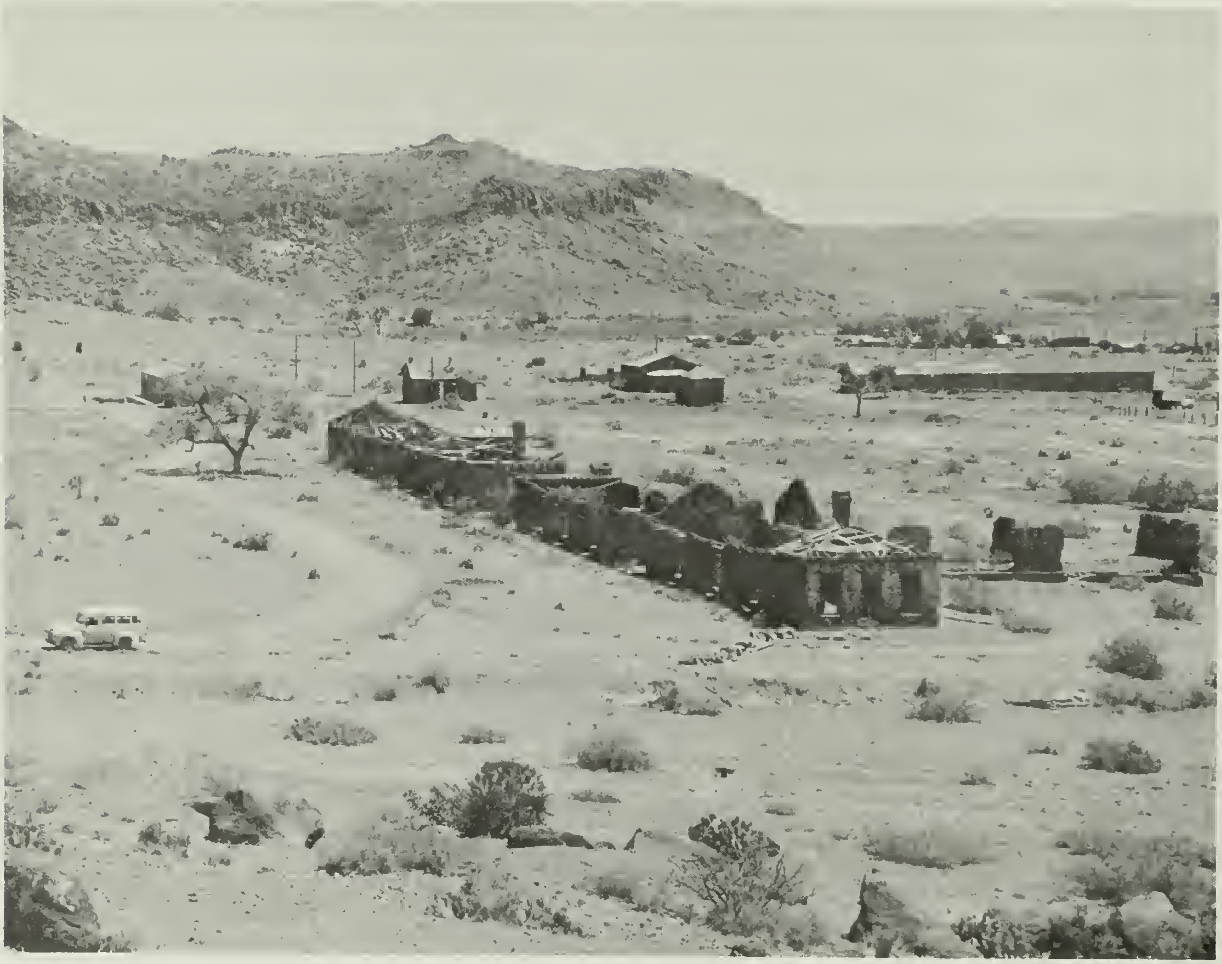


FIGURE 60. The 1870 enlisted men's barracks (in right foreground), Fort Davis National Historic Site. The photo was taken in 1960, before National Park Service status. Historic documents, drawings, and photographs provided ample evidence on which to base a restoration.

In most cases, however, both policy and economy dictate that historic, ruined adobe structures will also effectively serve their purpose if they are not restored, but are stabilized to maintain a ruined scene. In other words, preserve them "as is," and permit them to retain an atmosphere of abandonment.

In preserving an adobe structure, or the ruinous wall remnants of a structure, regardless of whether the end result will be partial restoration or a stabilized site, a choice must be made with respect to methods or materials to be used. In the present state-of-the-art, the hard reality is that there are only two basic choices: either stabilized or unstabilized adobe, used either as mortar or in brick form. It has been implied earlier in this work that an all-purpose chemical surface spray which will preserve adobe indefinitely has not yet been developed. For more than 40 years the National Park Service has experimented with chemical sprays which will both harden and weatherproof adobe. Many of these experiments were conducted by Charlie R. Steen, beginning at Casa Grande Ruins National Monument. None was successful. However, from a combination of Steen's experiments and those of the

Ruins Stabilization Unit, plus the modification and adaptation of developments in the commercial field, two valuable lessons were learned: 1) certain silicones are excellent for waterproofing hard surfaces such as soil-cement, and 2) the use of additives in manufacturing simulated adobes greatly increases their longevity.

The use of either plain or stabilized adobe modular units should be thoroughly planned and tested for any given area. Usually, soil for historic-adobe buildings was obtained within a short distance of those buildings. Thus, at Fort Bowie National Historic Site at least one or two of the original borrow pits were located by the ruins stabilization crew in advance of proposed work. Various soils from the vicinity should be tested as described in Chapter 3, and either experimental adobe bricks, soil-cement bricks, or soil

FIGURE 61. A view of the Fort Davis barracks after restoration. The ruinous shell seen in figure 60 was veneered with hand molded soil cement bricks, 4" x 4" x 12". They were made with one part portland cement (untinted), three parts unwashed sand, and three parts native soil. The bricks laid in masonry mortar with rough joints, set with spalls, were wire-brushed. Original walls were pared down where required to accommodate the veneer brick and to retain original wall dimensions and thickness. Bond beams were installed at roof line to support the restored, hipped, shingled roof. The soil cement brick walls were painted with white cement paint, although originally they were whitewashed. The building is used functionally today as the Visitor Center. Cost of the restoration: $129,000 or $12.90 per square foot.

bricks with chemical additives should be made and tested for matching color and texture, and for weathering and durability. A year or more lead time is not too long for selecting and testing materials to insure satisfactory results on any project.

Manufacture of Adobe Brick

The manufacture of adobe and stabilized adobe is briefly outlined below together with some of the formulas which have been used successfully. It cannot be emphasized too strongly that suitable building blocks for any given area depend on exhaustive tests with local soils and various formulas followed by accelerated weathering tests and systematic observations similar to those described in Appendix 1. Hence, the discussion below must be considered as a guideline only. Local conditions may vary to the extent that some of the formulas cited may have to be radically changed and, in some instances, may not be suitable at all.

Adobe and stabilized-earth blocks are molded in two ways: with a machine press, or by casting the plastic-soil material in forms by hand.

Several earth-block presses are on the market. One of these devices is the CINVA-RAM block press. Evolved by the Inter-American Housing Center (CINVA) in Bogota, Columbia, South America, the all steel press consists of a mold box in which slightly moist earth or earth with cement or chemical additives is compressed by a hand-operated piston and lever system. The press is portable, weighing about 130 pounds. The three basic operations in making the compressed blocks are: (1) loading the mold box, (2) compressing the mix, and (3) ejecting the finished product. The compressed block can be removed immediately from the press without the use of a pallet. The press is made by Metalibec Ltda, Apartado Aereo 11798, Bogota, Columbia, a subsidiary of International Basic Economy Corporation in New York. Bellows-Valvair, a division of IBEC, 200 W. Exchange Street, Akron, Ohio 44309, are distributors of the CINVA-RAM press for the United States and Canada. Their selling price for the press in 1967 was $175, F. O. B. their warehouse, Tallmadge, Ohio.

The blocks made from these devices have two advantages over cast blocks. The press-made blocks are more uniform in size and shape. They are usually stronger—as much as several times as strong. But the presses make only one block at a time, and production is slower than casting. The National Bureau of Standards tested pressurized blocks using a laboratory-machine press which produced a block of similar quality to the CINVA-RAM block. The mix employed was a soil containing 46 percent sand and 46 percent silt and clay, with 8 percent portland cement. Blocks withstood pressures up to 800 pounds per square inch compressive strength (U. S. National Bureau of Standards; Building Materials Structures Report BMS 78). This compares with 100 p. s. i. for hand-molded adobes, and about 400 p. s. i. for hand-molded soil-cement adobes of the same formula used in the block press.

Press-made blocks are difficult to antique. Uniformity, and the use of structurally modular units are desirable in modern construction, but in historic adobe construction the original blocks which must be matched are usually weathered and rounded along exposed faces. To achieve this effect, it is easier to make a slumped block in a hand form and to texture the surface which will be exposed with a brush or other tool before the block has completely "set."

Hand forms for molding bricks may be made to mold any number of bricks. At Fort Bowie National Historic Site, the Ruins Stabilization crew made a form out of 1x6 lumber which molded six adobes at a time, in the most common size of 4x8x16. Lining the form with sheet aluminum made it easier to use.

After selecting the soil, sample blocks should be made and permitted to dry. If the sample warps or cracks upon drying, there is too much clay or loam in the soil and sand must be added to make a satisfactory building block. If the sample block crumbles, there is too much sand in the soil, and clay should be added. A distinguished Southwestern architect and authority on adobe (Lumpkins, 1971, p. 9) presents the following mechanical characteristics for determining whether a soil will make good adobes:

1. It is easy to mix with shovel or hoe when water is added. The soil should part free of the tool and should not gum or stick.

2. It should not fall apart when turned with a shovel into a small 8-inch-high mound.

3. It should slip free of the mold when the frame is lifted.

4. When left to dry it should not curl, warp or crack.

5. When dry the block should be easily moved, with little tendency to break or chip off at the corners.

6. Light to moderate rains of a 10 to 15 minute period should show little erosion or washing of the adobe brick.

Aside from the fact that soil for adobe bricks should be well graded with proper amounts of clay and sand, it should also be relatively free of humus. Soils containing alkali, caliche, or gypsum should not be used.

As Lumpkins (1971, p. 9) further points out, adobes that are not thoroughly dry should not be placed in a wall. He suggests that "to test for dryness, the block should be broken in two. If the outer edges are lighter than the core area, don't use; allow more time for drying. In the summer most soils will dry ready for use in from 30 to 60 days after the bricks are stacked."

An empirical field test for strength of cured adobe bricks is as follows: drop an adobe from waist height to the ground; if the adobe does not break, it is strong enough.

While manual labor is, of course, the historical method of brickmaking (which involved mixing the mud by hand-hoe in a pit), modern power-operated mixers are the choice today because of high labor costs. A hoe-type plaster mixer also does a more thorough job. Once the proper formula for either adobe or stabilized adobe has been determined, the ingredients should be carefully measured for each mix. Next to composition of the soil, the essential control for adobe brick is in the moisture content. The allowable limits range from 16 to 20 percent by weight. If moisture content is excessive, the mixture will be too thin and the block will slump excessively when the form is removed, and there will be serious shrinkage cracks in the dry block. Adobe bricks are cured by air-drying, while soil-cement simulated adobes must be damp cured for a week. To conserve water, the stabilized soil-cement adobes should be covered with damp burlap which, in turn, is covered with polyethylene sheeting. On the driest of days, usually only one or two wettings of the burlap is necessary.

Most adobe experts today do not advocate the admixture of straw or other vegetal fibers to the adobe mix. Although straw mixed with the soil may reduce excessive cracking, it also provides available channels through the block for the immediate conduction of water, increasing the effects of capillary action.

To compute the number of adobe bricks required per square foot of wall of any thickness, obtain the number of square inches in the face of one brick, including the thickness of the mortar joints and divide 144 by the result. For example, assume that a brick 16 inches long, 3 inches high and 8 inches wide is being used, and that both the vertical and horizontal joints will be 1/2 inch thick. A brick 16 inches long, plus 1/2 inch for the vertical, or end mortar joint, makes a total length of 16 1/2 inches. A brick 3 inches high, plus 1/2 inch for the horizontal or bed-mortar joint, makes the total height of each brick course 3 1/2 inches. Then 16 1/2 x3 1/2 inches = 57 3/4 square inches on the face. Dividing 144 by 57 3/4= 2.49 or 2 1/2 bricks per square foot of an 8-inch wide wall (one brick thick). If the wall is 16 to 18 inches (2 bricks) thick, 2 x 2 1/2 = five bricks per square foot. It may be mentioned that considerable stabilization requires veneering which may involve a brick only 3 to 4 inches wide rather than 8 inches, in which case a divider may be placed in the form, thus cutting the space in half lengthwise. While the number of bricks required per square foot of wall area remains the same, twice as many bricks can be made with the same amount of mix.

Similarly, by computing the number of cubic inches of mortar surrounding one brick when laid in the wall, dividing by 1,728, and multiplying the answer by the number of brick to be used, the number of cubic feet of mortar required to lay the brick may be obtained.

The mortar for laying blocks should be of the same material as the block itself. There are interesting examples of differential weathering where dissimilar mortar was used. In several walls at Fort Bowie, adobes were laid in lime mortar. It is probable that these same walls were originally covered with lime plaster.

Turning now to a discussion of stabilized adobe, it should be understood at the outset that there is disagreement among experts as to the relative merits of using stabilized adobe between plain adobe block construction, and the stabilized block where used for purposes of either restoration or stabilization. The addition of some of the stabilizers used today will change the color and appearance of the adobe block. If this objection can be overcome by surface texturing and integral tinting, or if the block work is to be covered by other materials such as plaster or paint, then the use of a durable, weatherproof block is highly desirable. It should be pointed out, however, that even though the original source of soil may be used on a given structure, it is very difficult to make plain adobes in any quantity where color and texture matches exactly those in the historic wall into which they are being integrated. Given enough time for experimentation with local materials in advance of a project, it is usually possible to come up with a suitable stabilized block. At any rate, current consensus in the adobe areas of the National Park Service is that, for reasons of policy and economy, stabilized block work which will need less repair or replacement in the future should be the objective.

Stabilization of Adobe Brick

There are several methods for stabilizing adobe brick, and only those which are commonly used or have been tested and found effective in varying degrees will be mentioned. The addition of a stabilizer in no way affects the choice of soil or sand-clay proportions previously outlined.

Two methods for stabilizing adobe bricks have already been mentioned. One is with the use of cement and mortar color admixtures, and the other is with the addition of an emulsified asphalt or bituminous stabilizer especially designed for the purpose. Instructions for making soil-cement and bituminous-treated adobes are identical to the methods outlined for the mortar in Chapter 3, under the sections entitled "Soil-Cement Mortar" and "Soil-Bitumen Mortar," with the exception that about 5 to 10 percent less water is required. If a CINVA-RAM or other block press is used, water for the mix must be held to an adsolute minimum, and as with all other mixes described, all ingredients must be thoroughly pulverized and mixed. Bricks made with block presses also require 4 to 6 percent less cement because of compaction. When using a block press, a simple test may be made to determine the correct amount of moisture by squeezing hard a ball of the soil mix in the palm of the hand. If the ball can be broken in two without crumbling and without leaving any moisture on the hand, the moisture content is correct. Obviously, the tendency is to use too much water. During the mixing of material to be block-pressed, the mix appears just slightly moist. If any water is visible, the mix is too wet.

Some representative formulas used on stabilization jobs in Southwestern adobe areas are listed below along with notes on coloration. At Fort Bowie, the mix consisted of six parts local, well-graded soil, one part portland cement, and mortar color. Three coloring mixes were evolved in order to achieve the several color shades of the bricks. For a buff color, one-fourth of a one pound coffee can of Desert Tan mortar color, and one can of Sunset Orange was premixed dry with each sack of portland cement. To produce a reddish adobe, 25 percent of the normal brownish soil was replaced with a reddish clay, using the same mortar color combination in the stock mix of cement as before. Gray adobe walls were matched by using one-fourth can of Desert Tan added to the stock mix of one bag of portland cement. Sunset Orange and Desert Tan are products of the Tamms Mortar Colors, Inc., 1222 Ardmore Ave., Itasca, Ill. 60143 (Morris, 1967, pp. 1,2).

At Pecos, in the 1969 stabilization of the 18th-century mission church, the following formula was used: four parts local soil screened through 1/4-inch mesh, two parts concrete sand, and one part stock mix. The stock mix consisted of 1 cup

of No. 6803 Frank D. Davis Brown Mortar Color mixed into one bag of portland cement. The cement color was specially formulated for the National Park Service by a private firm, Frank D. Davis Company, Cement Colors, 3285 East 26th St., Los Angeles, Calif., based on the soil sample sent to the firm in 1968.

The formula for soil-cement currently used for stabilization and repair work at Fort Union National Monument is listed as follows: 1 1/2 cubic feet of concrete sand, 1 1/2 cubic feet of local soil screened through 1/4-inch mesh, 1 pound burnt sienna dry-mortar color, 1/4 pound raw umber dry-mortar color, and 6 pounds portland cement. These quantities make up one batch of mix.

At Fort Davis National Historic Site the formula currently in use is: three parts concrete sand, three parts local soil screened in 1/4-inch mesh, and one part stock mix. The stock mix is one cup of Tamms Sunset Orange mixed with one sack of portland cement.

From the above formulas it will be seen that for sites in the Southwestern United States generally, about 43 percent by volume each of sand and soil, and 14 percent by volume of portland cement (including various mortar colors) has given the best results. Only through trial and error, and by advance, systematic experimentation with local materials, will the project supervisor determine the optimum mix for a given area.

An unusual adaptation of soil-cement is currently employed on extremely eroded walls at Fort Bowie. Soil-cement in fairly heavy amounts, one to three inches in thickness, is applied to moistened walls. The surface is left rough, coinciding with the texture, the uneven surface, and outline of the original wall. The surface of the soil-cement is then scored with a tool in such manner that the scored lines coincide closely with the covered vertical and horizontal mortar joints. These scored joints are then pointed with a lighter colored soil-cement mortar matching the original. The finished product is a simulated, weathered adobe wall surface, and is a much quicker, more economical method than veneering and capping with stabilized adobes. Treated with a silicone (Daracone), the effective life by this method is 20 years or longer. Similar soil-cement veneers, both formed or hand-applied in Compounds A and B at Casa Grande, have been in place for 17 years. The color there had become somewhat objectionable, due not to the original mix, but to recent patches. The surface was given a bonded mud mortar wash in 1972 which can be repeated at several-year intervals as required.

Aside from making stabilized adobe with cement or bitumuls, there is now a move to use various new chemicals and additives with water and soil to make a strong, weather-resistant brick which has the same color and texture as a plain adobe brick. Only two of the more promising chemicals will be mentioned.

One of the newer soil stabilizers in the plastic resin class is Soil Seal Concentrate, developed in the commercial field as a patented spray to halt erosion along soil or sand banks. It is manufactured by the Soil Seal Corporation, 6311 Rutland Ave., Riverside, Calif. The cost in 1972 was $3.84 per gallon. The firm's literature describes it as a formulation of "balanced copolymers," apparently a methacrylate compound which is formulated as a plastic emulsion miscible in water. Recommended use varies from 5 to 15 percent Soil Seal mixed with water. Example: a 10 percent solution would be mixed with nine parts water, one part Soil Seal.

Steen reports that in about 1965, Soil Seal was "mixed into adobe and a house was built of the bricks made. The house has stood in Southern California since then. It is unplastered and reportedly shows no sign of deterioration or erosion" (Steen, n. d. p. 8). Both Steen and the staff at Pecos National Monument experimented extensively with Soil Seal in 1969-1970. The following formulas ae now being used successfully at Pecos in making stabilized adobes for repair work on the mission and convent. For interior, non-exposed work, such as the partly restored kiva, the following mix is used: three parts sand, three parts soil, and Soil Seal and water mixed in the ratio of 1 to 15 or 20. For exterior, exposed adobes, the Soil-Seal-water ratio is 1 to 10.

Some of these adobes have been in place about two years. During periods of heavy precipitation they become quite soaked. Nevertheless, they display remarkable cohesiveness, dry out rapidly, and have good resiliency during freeze-thaw periods (personal communication, Gary Matlock, supervisory archeologist). A value judgment indicates that it is too early to determine accurately the projected effective life of the plasticized resin in these adobes.

Another chemical which has come into prominence and is undergoing rather intensive experimentation in California and New Mexico is Acryl-60, an acrylic liquid polymer for curing and patching concrete and masonry (Steen, 1970, p.6). Steen also reports that this chemical has been successfully used as a spray to harden and waterproof adobe walls in the California State Park System. Manufactured and sold by Standard Drywall Products, Inc., New Eagle, Pennsylvania, 15067, Acryl-60 sold at $4.68 per gallon in 1972.

Simultaneously with their experiments on Soil Seal Concentrate, Steen and the Pecos staff concluded successful test blocks with Acryl-60 as an additive in making adobes. A section of veneer and capping of adobes now in place toward the top of the north wall of the transept of the 18th-century mission church were made with the following mix: three parts sand, three parts soil, and Acryl-60 and water in the ratio of 1 to 15.

A stronger, more durable brick is being used in the California State Parks (Johnson, n.d.) employing Acryl-60 as an additive to soil-cement with the following formula: one part cement, eight to ten parts soil, and 1 quart of Acryl-60 to each cubic foot of mix by volume. Add this material to the mixing water (one part Acryl-60 to three parts water). Mortar color is added as required.

From the above discussion it will be seen that a perfect solution to the vexing problem of preserving ruined adobe structures has not been discovered. Most of the methods described are long term maintenance or holding actions. If they had not been implemented, however, few of the treated walls described would remain today. While advances in chemical and coating technology can greatly assist in inhibiting deterioration of adobe, it is doubtful that they will be successful in halting it altogether. Solidification and induration of adobe-in-place by electro-chemical means, by infra-red baking, and by methods yet to be discovered, are certainly not beyond the realm of the possible. Highly sophisticated and technical experiments conducted through expensive interdisciplinary research may be required to solve this problem completely.

5 Recording

A stabilization record is a structural history of a site or an architectural unit of that site: a room, a wall or a doorway. It is intended to provide full information on the original condition of the unit, including any inherent structural weaknesses, previous protective or preservation measures and, in detail, the techniques and materials employed to bring the unit to its present state of preservation. It is advantageous to record the various steps of unusual or difficult solutions, of new or experimental techniques and special features of the site or project. The amount of detail that will be required will vary with the size and complexity of the individual project, ranging from the brief description necessary for a wall fragment uncovered in grading operations, to the full reporting required to document the realignment of walls and the installation of integral members.

COMPREHENSIVE STABILIZATION RECORDS

The preparation of comprehensive stabilization records is time-consuming. It may require a good deal of research into the past history of the structure. One example is the comprehensive stabilization of Talus Unit, excavated and partly stabilized by the Museum of New Mexico, and on which there are the excavator's notes but no publication. Sufficient time must be scheduled to permit the search for and inclusion of pertinent data in the individual room records. Stub walls and partition walls are often removed by the excavator to facilitate the search for or clearing of lower structures, and it is important to know the extent and former location of these in planning the perservation of any area. It is also of particular value to know the location of loosely backfilled areas, for these often hide evidence of undercutting and weakness, and pose problems in surface drainage.

In addition, stabilization records in conjunction with cost accounts are of inestimable value in developing budgets for future programs.

RECORD SHEETS

The permanent record sheets designed for the Southwestern National Monuments about 1937, and still in use at the Ruins Stabilization Unit, are self-explanatory (see examples, figs. 62-64). With a few minor changes in headings, which can be made on the job, they can be used for a wide variety of work. They can be attached to a clip board or binder, and most of the entries can be made in the field. Accumulative data can be entered from a daily log at the completion of each unit. The presentation of data can be somewhat modified in practice, depending on the kind of site and amount of work required. There are two pages to each stabilization record, a "first sheet" for references, justification, orientation and architectural background. Where a series of small adjacent rooms or similar units have the same references, justification, orientation and the same architectural background, only one "first sheet" need be filled in to include a group of contiguous rooms. A separate "second sheet" will

be used to detail the condition of the ruin prior to the start of work, and the previous and current repairs.

PHOTOGRAPHIC COVERAGE

The individual record sheets should be followed by pages showing at least one "before" and one "after" picture. Extensive photographic coverage is desirable and may include general overall views showing the conditions of adjacent terrain which may affect the site, as well as detailed shots of specific techniques. Where a portion of a structure is to be reset or will have to be replaced, as in seting integral members, it is a decided advantage to take the photographs well in advance of the actual work. Enlarged prints can then be used as guides in resetting masonry, to obtain authentic contours of wall tops, and for filling in small details. If the work is large, and there are many small details, the addition of vertical and horizontal scales in the photograph will insure accurate dimensioning.

The maximum size print that can be used to show both a "before" and "after" on the same page is 4 by 5 inches. In special cases it will be convenient to have general overall pictures in 8x10's mounted on a single page. A good photographer, using 35 mm. film and making careful enlargements, can produce excellent 4x5 prints at a considerable savings in cost. However, most supervisory personnel will not always have good darkroom facilities at their disposal and, unless custom finishing is available, commercial 4x5 enlargements are not apt to be as satisfactory as those made from larger negatives. The 4x5 press camera and contact prints are the most useful and result in the greatest savings in time.

Materials and Processes

The following are random observations based on the somewhat over 15,000 negatives now on file at the Ruins Stabilization Unit.

In smaller communities, check local services before entrusting them with film for development. Most photofinishers use DK-20, a long-lived developer that is fair for some film, but totally unsuited for materials in the Eastman Royal Pan family. Negatives are apt to be too thin for use. The most satisfactory system has been to develop negatives in the field. This permits an immediate quality check, and the photographs can be re-taken if necessary.

Daylight tanks holding a dozen sheets of film, prepared chemicals, and washing aids or hypo eliminators reduce the work involved. The use of a hardener in warm weather, and a wetting agent before drying, aid in the production of good quality negatives. With the use of a hypo eliminator, archival quality negatives and prints with long-range keeping qualities can be made. However, this service is not always obtainable from commercial establishments.

The film used will depend primarily on personal preference and familiarity with the characteristics of a particular brand or kind. In general, extremely high speed types are to be avoided and the best results are had with medium speed film with fairly good contrast. The use of filters with panchromatic films is often a decided advantage. On the other hand, some of the most satisfactory photographs in the files of the Ruins Stabilization Unit are the results of attempting to duplicate old glass plate pictures taken by Jackson and Mindeleff. These were taken with an old view camera using Eastman Commercial film with a slow orthochromatic emulsion. Skies were lost, but the rendition of surface texture and detail in masonry is excellent.

Photographic coverage of a site takes time and should be started far enough in advance so that advantage can be taken of the correct position of the sun for good lighting. In the Southwest, one of the major defects of contact prints are areas of deep shadow in which all detail is lost. These shadows can be somewhat compensated for in developing, but it is far better to take the picture when the lighting is optimum for the area to be shown. If it is impossible to do this with natural sunlight and reflectors, it is well to remember that flash bulbs for fill-in lighting produce more contrast which more closely approximates sunlight than the electronic speedlights. Supplementary lighting is good for close-ups of details and at moderate distances, but it requires more experience and often extensive equipment for use in large areas. Some of the best architectural

record shots are made on overcast days with negatives developed to a fairly high contrast. A vexing problem, which is rarely solved by additional lighting, is that of making one specific part of a structure stand out in a photograph without having it confused with extraneous background material that cannot be kept out of the picture. An experienced photographer with a relatively long lens can usually throw the background out of focus. A large, lightweight piece of canvas can be held as a background cloth to isolate specific walls or sections; the improvement in clarity is worthwhile.

The only satisfactory method of mounting prints for the record pages is thermosetting mounting tissue. While a press is an advantage, small quantities can be pressed with an ordinary household iron that has settings for different fabrics. One way to avoid the use of mounting tissue, and the resulting extra bulk, is to print the photographs two to a page on ad-type paper. At the time the Southwest Regional Office of the National Park Service was operating a photo lab, all the Ruins Stabilization Unit's records were printed on this paper, which will accept typewriter impressions, and most of them were excellent. Very high commercial costs and the reluctance of most photofinishers to attempt printing two negatives of differing densities on a single contact sheet have prevented the continuing use of ad-type paper.

SUPPLEMENTAL RECORDS

Stabilization forms and photographic pages such as those depicted in figures 62-64 should be used regularly for all archeological stabilization work and for historic structures whenever possible. These can be supplemented, particularly in historic buildings, by additional means of recording. Entering repairs or other changes on Historic American Building Survey (HABS) records, or comparable measured drawings (where available) is a particularly convenient means of supplementary recording. An accurate ground plan is a necessity for an archeological site of any size. While not approaching the detail of HABS sheets, ground plans can be used to show type and location of work accomplished. While successive jobs on a building over a period of years will be shown in different reports, large ground plans are an effective medium for recording and presenting the cumulative total of preservation measures.

MAINTENANCE RECORDS

Recording maintenance work poses a number of problems. Minor maintenance such as cleaning drains and the resetting of small areas of masonry dislodged by visitor traffic does not require entries to stabilization records if the work does not change the structural history of the unit. However, such work should be recorded when a change is made in materials or in location of accessory items such as drains. For example, a good deal of capping in the Southwest 30 years ago was accomplished with soil-bitumen mortar. It has become necessary to replace some of this within the last few years, particularly on low walls close to self-guided trails. When stones in this capping are set in tinted concrete mortar, it constitutes a change in materials and, though the same stone is used and the appearance of the unit has not been altered, the substitution of concrete for soil-bitumen should be recorded.

In such instances, unless the maintenance is very extensive, it is not necessary to make a new, two-sheet stabilization record. This is time consuming and results in excessive duplication. For ordinary maintenance of any site, one new "first sheet" can be used to cover the entire site. The principal entry will note that this is maintenance work and that the detailed entries can be found in the comprehensive record. Give the year and page number of this comprehensive record. Then it will only be necessary to enter the maintenance work on the "second sheet." Ordinarily, stabilization records for each site are bound in permanent volumes, by years. Since maintenance records are seldom very extensive, this results in some rather thin-bound volumes, but this system has proven more effective than attempting to add additional data to the larger comprehensive records. If there are a few sites

RUINS STABILIZATION RECORD--FIRST SHEET

Location FORT UNION N.M. Date 7/14/60

Name of ruin ——— Building 3-330

Room 331 Kiva ——— Wall E. S. W. Floor, roof ———

References to publications and justifications for job: INITIAL STABILIZATION OF BUILDING FOLLOWING PROCUREMENT BY NATIONAL PARK SERVICE

Architecture

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning, etc.)

CONTEMPORANEOUS WITH CONTIGUOUS ROOMS.
NO EVIDENCE OF BURNING. SINGLE STORY.

Floor (type, additional notes) PROBABLY PACKED EARTH.

Roof (type, additional notes) NONE REMAINING.

Details (notes on doorways, lintels, etc.) BRICK COPING ATOP WING WALL READY TO FALL. WEST WALL IS ALSO THE EAST WALL OF ROOM 321. LITTLE REMAINS OF EAST WALL; ALMOST NONE OF NORTH WALL STANDING. FOUNDATION STONES MISSING FROM WING WALL ON EAST END.

FIGURE 62. An example of a "first sheet" used for the stabilization records at Fort Union National Monument. It should include information, when available, on references, justification, orientation, and the architectural background.

RUINS STABILIZATION RECORD--SECOND SHEET

Location FORT UNION N.M. Room or kiva 3-331

Date work started 9/4/58 Date work completed 5/12/59

Man days of labor 28 1/4 Cost of materials $106.08

Archeologist REX L. WILSON

Condition on date when work started. Masonry ALL WALLS NEED CAPPING. BRICKS COPING IN URGENT NEED OF REINFORCEMENT. ADOBES BADLY ERODED AWAY UNDER COPING IN WING WALL.

Repair or reconstruction previous to this work NONE

Materials, construction, and technique in making repairs or accomplishing job WING WALL: MISSING FOUNDATION STONES WERE RESET IN CEMENT MORTARS. AFTER THE BRICK COPING HAD BEEN REALIGNED WITH MINE JACKS, A GRIDWORK OF ANGLE IRON PLACED AT A RIGHT ANGLE TO IT ON THE EAST SIDE OF THE ROOM'S EAST WALL. THE LARGER-- (Attach additional sheets if needed.)

Note: Place "before" and "after" pictures on blank bond sheets, caption, and keep with these record sheets. Include "during" pictures to show interesting or important details or techniques.

FIGURE 63. An example of a "second sheet" used at Fort Union National Monument. Second sheets may be used where architectural units have the same references, justification, and architectural background.

in an area, and two or more receive maintenance in the same year, such records can be bound together.

FIELD NOTES

Some form of a daily log or field notes should be kept, not only to record progress, but to keep an accurate record of man-days and materials expended. While for many smaller projects the required data for the record can be entered directly on the sheets in the field, some additional record will be required from which to take the amounts of materials used. An engineer's field book is convenient to carry and easy to use if the tendency to crowd small pages is avoided. Separate columns can be used for materials and calculation of man-days expended.

If one unit, such as a single wall or room, is being stabilized at a time, it is a simple matter to arrive at the total materials used. However, several small units will probably run concurrently, and materials such as concrete mortar, soil-cement, etc., will be distributed from a central point. In such cases, the work expenditures can be measured at the end of each day and the materials prorated among the separate jobs. If a little effort is spent at the beginning to determine just how much cement or bitumen or other material is required for a definite unit of work (a square foot of capping or a cubic foot of wall repair, etc.,) and this is checked from time to time, the total materials used can be more easily prorated among the various individual projects.

RECORDING OF EXPENSES

While the individual record sheets have entries for individual architectural unit-costs—man-days and materials per room or area—it is more realistic to keep total project costs. This permits the inclusion of truck and equipment costs, supervision, and other overhead charges that cannot be accurately prorated among many small units. At any rate, whether or not individual room expenses are kept, some record should be made of total project costs. These can then be broken down into the most convenient units for future estimates. Breaking this back down into the cost per room is one method of obtaining quick estimates. Another method is to work out costs per unit-of-work, so much per lineal foot of capping on walls 12 feet high or over, so much for lower walls, the cost of patching a square foot of masonry, or the cost of grading and draining a square yard of room interior. This unit-of-work method provides slightly more accurate results, although it does take more time to work up and more time to apply.

BUILDING 3-330,
ROOM 331,
WING WALL,
BEFORE
STABILIZATION

BUILDING 3-330,
ROOM 331,
WING WALL,
AFTER
STABILIZATION

FIGURE 64. All ruins stabilization records should include before and after pictures attached to separate sheets such as the ones above for Fort Union National Monument.

Pueblo Bonito, Chaco Canyon National Monument, Bloomfield, New Mexico. Four distinct masonry styles through two main building periods are evident in this, the largest prehistoric "apartment house" north of the Valley of Mexico. Modern repair and stabilization maintain this ruin at the original profile and elevation of walls and features uncovered during two major excavations, performed in 1897-99 by the Hyde Exploring Expedition, and in 1921-27 by the National Geographic Society.

APPENDIX 1

Accelerated Weathering Tests

This section describes well-controlled, accelerated weathering tests with various commercial sprays to evaluate water repellency on adobe walls at Fort Union National Monument. The findings herein are primarily the results of research conducted by Rex L. Wilson (1956-1960, Mss., vol. I, pp. 11-17).

Silicone Preservatives

There are more than 153 thousand square feet of standing adobe walls at Fort Union. Mindful of this figure, considerable thought entered into the purchase and application of silicone preservatives. Small-scale applications of two well-known products, Dewey and Almy's Daracone and Dow Corning's Silaneal 772, indicated that we could expect one gallon of a silicone solution to cover anywhere from 75 to 100 square feet. Daracone, priced about $5 per gallon, seemed extremely expensive in view of the number and size walls that required treatment. Therefore, many silicone manufacturers were contacted in an attempt to find a product that could give similar protection for less money. After our experiments, we concluded that Silaneal 772, when diluted in water in the ratio of 1 to 9, would give about a 5 percent silicone on the walls for around 50 cents per gallon. Purchase of this product, therefore, seemed justified.

Nearly all Fort Union adobe walls have been generously sprayed with Silaneal. It will probably require several years' observation to make definite conclusions as to which of these products affords the best protection, but it seems safe to conclude, on the strength of present evidence, that Daracone and products with similar characteristics and prices are not *ten times* better than Silaneal for waterproofing adobe.

Most applications of silicone were made on completely dry walls with a homemade spraying device under sufficient pressure to provide a rundown of from 4 to 6 inches. The solution must necessarily reach and penetrate all cracks, large and small, to do an effective job and give fullest protection. Experiments have shown conclusively that constant rainfall will attack the minutest cracks, work behind the silicone crust and finally force it to fall away, leaving unprotected spots vulnerable to further erosion.

No preservative will withstand the abuse of a hailstorm of magnitude. Falling hail stones are known to have flaked off chunks of adobe up to 1/4th inch in thickness, a depth to which no known silicone product will penetrate. Because hail is common at Fort Union, we should plan to touch up or respray entire walls on a year-to-year basis. Periodic inspections for hail damage should be made immediately after a rain when damaged areas show up dark against the light background of protected adobe.

Experience with Silaneal 772 has shown that when the product has been applied and allowed to dry, it is absolutely impervious to further applications of the same product. It will not, however, shed certain other products, e.g., Daracone and Dow Corning's 770 Water Repellent, which contain wetting agents superior to water. Both these products and others like them could be

used in respraying hail-damaged walls. We have had some success at Fort Union with spraying the Silaneal 772 high on a damaged wall, allowing the solution to run down and find its way into cracks and chipped spots, thus re-establishing complete protection.

Costs of silicone preservatives and labor were not included in the reports for the individual rooms, but are considered building-by-building in table 3.

Experimentation with Silicone Preservatives

Two experimental walls were built in the corral section east of the warehouse district. The rock foundations are 1 1/2 feet wide and are about 6 inches above the surface of the ground. The longer of the two sections is 40 feet and the shorter is 20 feet. Ten sections of adobe wall were built upon the longer foundation, and five sections were built upon the 20-foot foundation. Each of the sections of adobe are 3 1/2 foot long, 1 foot wide, and five adobes (*ca.* 2 feet) high. The wall sections are 6 inches apart, and are numbered 1 through 15 with paint applied to the foundations. Sections 1, 2, and 3 were capped with soil-cement adobes; all others were left uncapped.

To facilitate measurement of weathering over a period of time, 20d nails were driven into the walls at various places, with their heads flush with the outer edges of the adobes. Then, using a brush and allowing considerable rundown, the walls were treated as follows:

TEST SECTION	SOLUTION USED
1	1 part DC-772 diluted in 6 parts water.
2	1 part DC-772 diluted in 9 parts water.
3	Klear-Film.
4	1 part DC-772 diluted in 12 parts water.
5	Untreated, to be used as control.
6	1 part DC-772 diluted in 2 parts water.
7	1 part DC-772 diluted in 3 parts water.
8	1 part DC-772 diluted in 4 parts water.
9	1 part DC-772 diluted in 5 parts water.
10	Daracone.
11	1 part DC-772 diluted in 8 parts mineral spirits.
12	Hydrocide SX Colorless.
13	Hydrocide Colorless 101.
14	Polystyrene (plastic) in benzol.
15	1 part DC-772 diluted in 8 parts water.

Using a pump powered by a Jeep and mobile tank, water was applied with a garden hose sprinkler under sufficient pressure to simulate a gentle rainfall from the south at an angle of about 45 degrees from horizontal. Two or three sections of wall were treated in this manner at the same time. Neighboring sections that could not be well-flooded were covered with tarpaulins during the testing. Although the original plan for testing the experimental walls to the point of failure was not concluded, valid conclusions can be made. Table 4 indicates how far experiment had progressed up to August 8th, 1960.

TABLE 3. Costs of silicone preservatives at Fort Union National Monument.

Building Area	Gallons of Mix	Silicone Costs	Man-days Labor
Mechanics Corral	248	$124.00	3
Post Officers Quarters	58	29.00	3/4
Laundresses Quarters	43	21.00	3/4
Company Quarters	50	25.00	1
Depot Warehouses	335	167.50	5 1/4
Depot Offices and Quarters	242	121.00	3
Transportation Corral	5	2.50	0
Hospital	227	113.50	3
Sutlers Store	5	2.50	1/4
Arsenal	312	156.00	4 1/2
TOTALS	1,525	$762.50	21 1/2

Several light hailstorms were recorded at Fort Union between July 8, 1959 and August 8, 1960. They resulted in considerable abrasion to the test walls but with no appreciable precipitation. Therefore, precipitation falling as hail is not included in the table.

All Silaneal 772 applications, regardless of strength, appear to have held up equally well. The ready-mixed solutions of Daracone, Klear Film, Water Repellent, and Hydrocide Colorless SX also survived the experiment with results roughly equal to that of the Silaneal. It would appear that one product gives no better protection than the others.

Two of the solutions broke down completely under the effects of normal rainfall: Hydrocide Colorless 101 on Test Section 13, and Polysty-

TABLE 4. Normal and simulated precipitation (in inches) on selected test sections of walls at Fort Union National Monument.

Test Section	Date of Construction	Normal Precip-itation	Simulated Precip-itation	Total Precip-itation
1	7-8-59	22.83	19.37	42.20
2	7-8-59	22.83	19.37	42.20
3	7-8-59	22.83		22.83
4	7-8-59	22.83		22.83
5	7-8-59	22.83		22.83
6	8-10-59	19.76		19.76
7	8-10-59	19.76		19.76
8	8-10-59	19.76		19.76
9	8-10-59	19.76		19.76
10	8-10-59	19.76	32.10	51.86
11	8-10-59	19.76	32.10	51.86
12	8-10-59	19.76	12.75	32.51
13	8-10-59	19.76		19.76
14	8-10-59	19.76		19.76
15	8-10-59	19.76		19.76

TABLE 5. Depth of penetration (in inches) of various products in soil-cement and adobe.

Product	Depth of Penetration	
	Soil-Cement	Adobe
Daracone	5/32	1/8 to 5/32
DC-770 Water Repellent	1/8	3/32 to 7/32
Klear-Film	1/8	3/32 to 7/32
DC-772 Silaneal, 1 to 5	1/8	3/16
DC-772 Silaneal, 1 to 4	1/8 to 5/32	1/8 to 3/16
DC-772 Silaneal, 1 to 3	1/8 to 5/32	1/8 to 3/16
DC-772 Silaneal, 1 to 2	5/32	5/32 to 3/16

rene applied to Test Section 14. As of the date of this writing, any protection once afforded by the former product has completely vanished and little remains of the latter.

In addition, tests were made with individual soil-cement and regular adobes to determine the depth of penetration of the several silicone solutions applied to test walls. Each adobe was liberally brushed with a solution in the same manner as it was applied to the test walls. After being allowed to dry for several days, each adobe was broken and immersed in water. Depth of penetration of the several solutions was then measured. Most of the preparations tested penetrated soil-cement and regular adobe to an equal depth of about 1/8th inch. Specific results are given in table 5.

Despite claims made by manufacturers that their silicone products will not discolor adobe, it is quite evident that some do alter the original color. Hydrocide Colorless 101 temporarily bleached the adobe test wall. A very rich mixture of Dow Corning's Silaneal 772 likewise left a whitish deposit on the test wall which eventually disappeared. When applied at the specified ratio of 1 to 12 or at the richer 1 to 9, Silaneal did not appreciably change the appearance of adobe. Polystyrene, not a silicone but a plastic, darkens adobe substantially and eventually turns a yellowish color.

Casa Grande Ruins National Monument, Coolidge, Arizona. This site is the famous Compound A which contains the Casa Grande, or Big House, with its associated structures and refuse mounds. The Casa Grande, a massive walled structure containing three usable stories, was built of coursed caliche-earth, a desert soil with a high lime content. Recent stabilization methods (after this photograph was taken) consisted of either forming or veneering the low compound walls surrounding the Big House with soil cement, and treatment with water repellent silicones.

APPENDIX 2A

Wall Realignment and the Use of Adobes

Figures 62-64 are facsimilies of the stabilization record on wall realignment and the use of adobes for repair concealing integral reinforcement at Fort Union National Monument. These and similar forms for first and second sheets, and a sheet for attachment of photographs of ruins before and after stabilization, are in use at the National Park Service archeological center in Tucson.

RUINS STABILIZATION RECORD FIRST SHEET

Fort Union National Monument; Date: *July 14, 1960;* Building: *3-330;* Room: *331*; Feature: *wing wall;* Wall (N.S.E.W.): E S W.

Architecture

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning, etc.): *Contemporaneous with contiguous rooms. No evidence of burning. Single story.*

Floor (floor type; additional notes): *Probably packed earth.*

Details (notes on doorways, lintels, etc.): *Brick coping atop wing wall ready to fall. West wall is also the east wall of room 321. Little remains of east wall; almost none of north wall standing. Foundation stones missing from wing wall on east end.*

SECOND SHEET

Room No. *3-331;* Date work started: *Sept. 4, 1958;* date work finished: *May 12, 1959*; Man days of labor: *28 1/4*; Cost of materials: *$160.08.* Archeologist: *Rex L. Wilson;* Date: *July 14: 1960.*

Condition on date work started; masonry: *All walls need capping. Brick coping in urgent need of reinforcement. Adobes badly eroded away under coping in wing wall.*

Materials, construction, and technique in making repairs or accomplishing job: *Wing wall: Missing foundation stones were reset in cement mortar. After the brick coping had been realigned with mine jacks, a gridwork of angle iron was placed on the north side of the wall and welded to a smaller gridwork of angle iron placed at a right angle to it on the east side of the room's east wall. The larger gridwork consists of four 11'8" lengths of 2" x 1/8" angle iron placed vertically on the north side of the wall in intervals of 4' 9", 4' 4", and 5' 1". The westernmost vertical member is situated in the angle formed by the abutting walls.*

A collar of 2" x 1/8" angle iron was welded together and placed immediately under the brick coping. It was then welded to the vertical angle irons. The collar is 15' 3" long and 2' 6" wide. Two 11' 8" lengths of 2" x 1/8" angle iron was placed horizontally and welded to the vertical members. The upper piece is 1' 3" below the underside of the coping and the lower piece is placed midway in the wall 5' 10" above the top of the stone foundation. Resting directly upon the stone foundation is a 11' 8" length of 2" x 1/8" strap iron which is welded to the vertical lengths of angle iron.

The entire gridwork is held to the wall by lengths of 3/8" reinforcing rod placed at various points on the gridwork. They penetrate the wall, are welded to the gridwork on the north side, and are welded to strap iron washers imbedded in depressions hacked out of the adobe on the south face of the wall.

A short length of angle iron is welded diagonally to the strap iron and to the westernmost vertical angle iron.

Another gridwork is welded at a right angle to the extreme west end of the larger system. The smaller section is recessed in the east side of the abutting east wall of room 331. A single vertical 10' 5" length of 2" x 1/8" angle iron was placed 5' 11" north of the point where the east wall of room 331 abuts to the wing wall. The vertical member is welded to a horizontal 5' 11" length of 1 1/4" x 1/8" angle iron and to a 2" x 1/8" angle iron 5' 11" long. The uppermost horizontal piece (1 1/4" x 1/8") is situated 10' 5" above the top of the stone foundation and the other is placed 4' 7" below that. The vertical members are welded to a 5' 11" length of 2" x 1/8" strap iron resting upon the top of the foundation.

A final 6' length of 2" x 1/8" angle iron is welded diagonally from the angle iron placed in the corner formed by the abutting walls to the northernmost vertical member in the east wall of room 331.

After the completion of the steel installation a concrete cap was laid on top of the coping and painted red. Adobes were used on the east end and north side of the wing wall to conceal the steel gridwork and to further reinforce the wall. The new adobes were roughened to give the illusion of age. The wing wall was then sprayed with Dow Corning 129G Resin.

South, west, and east walls: Capped. Sprayed with Dow Corning 772 diluted in water at a ratio of 1 to 9.

APPENDIX 2B

Use of Steel and Concrete for Adobe Walls

These records describe the use of steel and concrete to stabilize adobe walls concealed with soil-cement bricks (figs. 65-76).

RUINS STABILIZATION RECORD
FIRST SHEET

Fort Union National Monument. Date: *April 29, 1960;* Building: *3-440;* Room: *443;* Feature: *Wing walls;* Wall (N.E.S.W.): *EW.*

Architecture

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning, etc.): *Contemporaneous with contiguous rooms. No evidence of burning. Single story.*

Floor (floor type; additional notes): *Probably had wood floor.*

Details (notes on doorways, lintels, etc.): North and south walls considered as north and south walls of Building 3-440. *East wall is west wall of room 442.*

SECOND SHEET

Room No.: *3-443;* Date work started: *June 1, 1957;* Date work finished: *June 17, 1959;* man days of labor: ca. 48 3/4; Cost of materials: *ca. $181.72;* Archeologist: *Rex L. Wilson;* date: *April 29, 1960.*

Condition on date work started. Masonry: *Coping on west wall in urgent need of stabilization.*

Materials, construction, and technique in making repairs or accomplishing job: *West wall: The largest remaining section of brick coping (35' 6" long) on top of 20-foot high walls was completely stabilized with steel, concrete and soil-cement bricks. Eight vertical channels, about 4' to 5' apart, were cut to a depth of about 6" in the east side of the adobe walls supporting the coping. Two additional channels, one directly opposing the other, were cut in the north and south sides of the wall which abuts the coping-bearing wall on the east, and are located about 4' out from the corner formed by the junction of the walls. Horizontal channels were also cut in the west wall, and one on each side of the abutting (east-west) wall, so as to intersect the verticals at regular intervals.*

An angle-iron framework, whose components were welded together, was then erected in the channels of both walls. The supporting base plate of 1/8" x 2" strap iron was placed in the lowest horizontal channel of all walls, and rests directly on the rock wall foundations. The vertical members (of 1/8" x 2" angle-iron in the west wall, and 1/8" x 1 1/4" angle-iron in the abutting wall) are supported at their lower ends by the strap iron. All other horizontal members except those at the top of the walls are 1/8" x 3/4" angle-iron.

At the top of that section of coping-bearing wall north of the abutting wall, two horizontal members of 1/8" x 2" angle-iron were welded in place. One is directly opposite the base of the

FIGURE 65. Building 3-450 (left) and building 3-440, west walls and coping, before stabilization. Fort Union National Monument.

FIGURE 66. Building 3-440, coping on west wall, during stabilization, Fort Union National Monument.

FIGURE 67. Building 3-440, coping on west wall, during stabilization. Fort Union National Monument.

FIGURE 68. Building 3-440, coping on west wall, during stabilization. Fort Union National Monument.

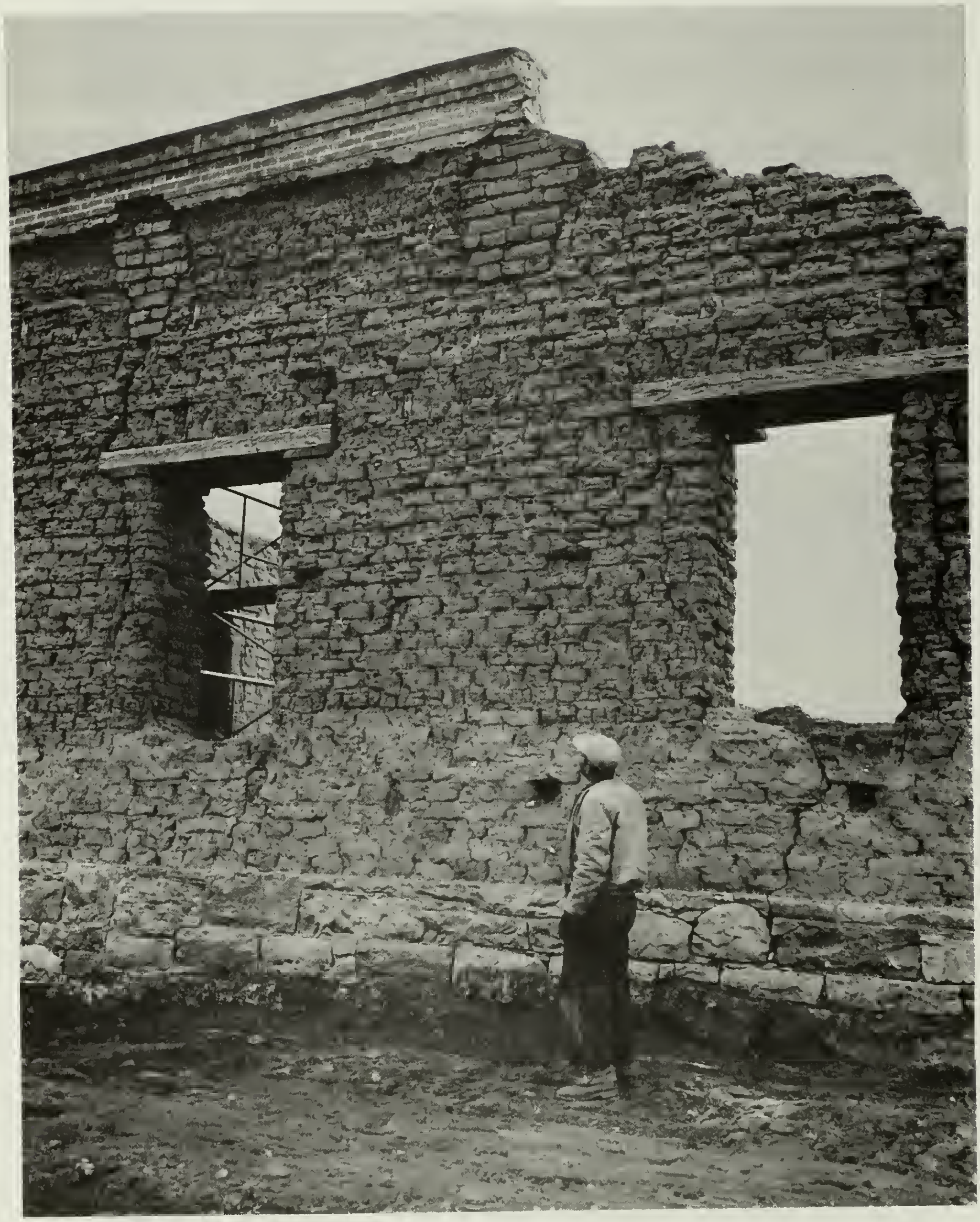


FIGURE 69. Building 3-440, west wall and coping, during stabilization. Fort Union National Monument.

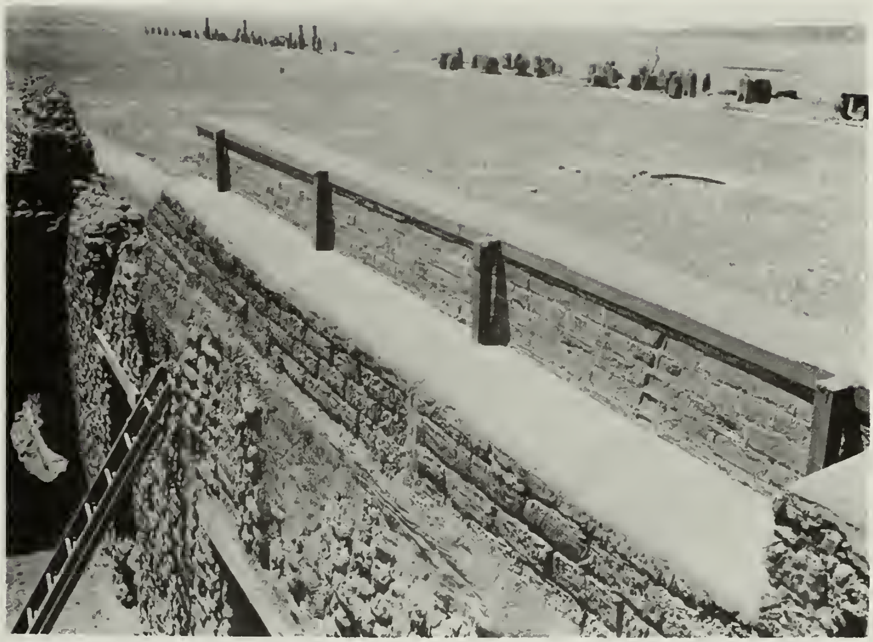


FIGURE 70. Building 3-440, south half of coping on west wall, during stabilization. Fort Union National Monument.

FIGURE 71. Building 3-440, northwest wing wall, during stabilization. Fort Union National Monument.

solid brick coping which is present now only on the west side of the wall. The other is immediately below and supports the horizontal veneer of brick which forms the top of this half of the coping, and which extends across the top to the east side of the wall. From the rigid framework on the east side of the wall, 1/8" x 2" modified angle-iron "hooks" extend across the top of the coping and down the west side about 7". These serve to hold the coping in place by preventing it from leaning outward at the top. To prevent the coping from dropping through collapse of the underlying adobe, only an edge of which supports the coping, a 1/8" x 2" angle-iron member was placed horizontally beneath the coping to provide support. It is secured to the framework on the opposite side of the wall by short lengths of 1/2" reinforcing rod, welded in place at each end. The remainder of this half of the framework is secured in a similar manner: an average of 3 short sections of 1/2" reinforcing rod for each vertical member penetrate the wall through drilled holes, and are welded to 6"-long strips of 1/8" x 2" strap iron sunk into the west side of the wall and to the vertical members in the east side.

The top of the wall under the brick veneer cap was almost completely eroded out. The area was cleaned of loose material, squared up and lined with metal lath. It was then rebuilt with soil-cement brick to provide a solid wall between the vertical members and the heavy, solid coping. There are no free-standing (and thus visible) steel members in this part of the wall, and thus maximum rigidity was provided.

The south half of the coping is more massive in construction than the north half, and there is no veneer or brick over the inner (east) portion of the adobe wall. Although the method of securing the coping at the top of the angle-iron framework is similar to that used to support the north half of the coping, more rigid construction was necessary because the vertical supports are free-standing for the top 22", approximately. Also, these top sections are offset to the west a distance of 10" from the vertical axes of the lower portions in such a manner as to place the side of the upper portions against the coping.

The free-standing sections overlap the remainder of the vertical supports, and are secured to them by an upper and a lower horizontal member

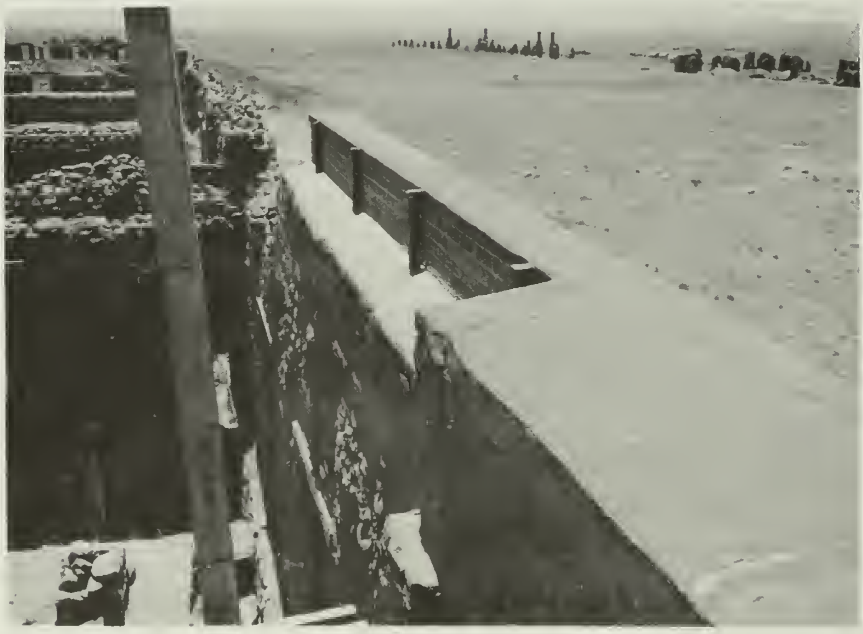


FIGURE 72. Building 3-440, coping on west wall, after stabilization. Fort Union National Monument.

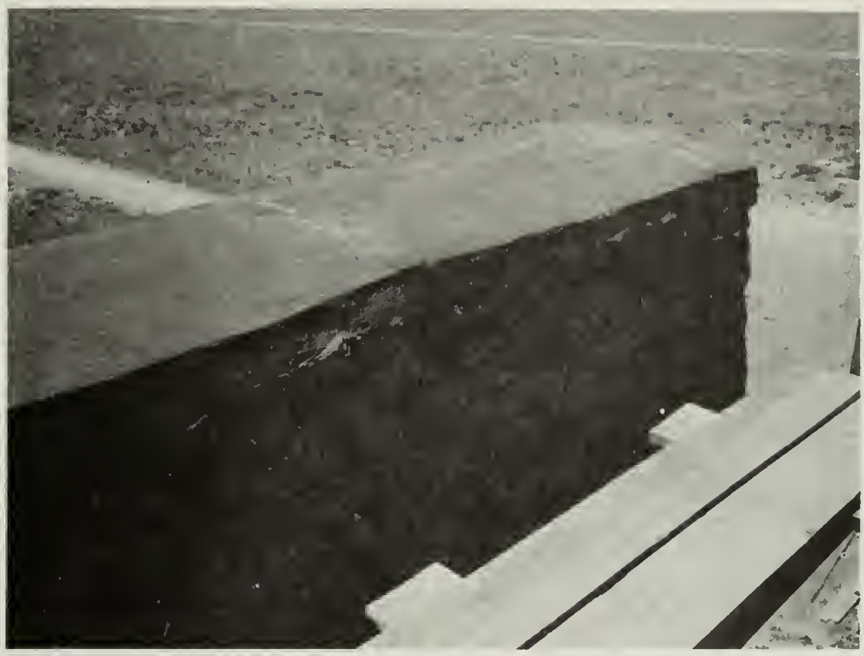


FIGURE 73. Building 3-440, coping on west wall, after stabilization. Fort Union National Monument.

FIGURE 74. Building 3-440, from the northeast, after stabilization. Fort Union National Monument.

FIGURE 75. Building 3-440, southwest corner, before stabilization. Fort Union National Monument.

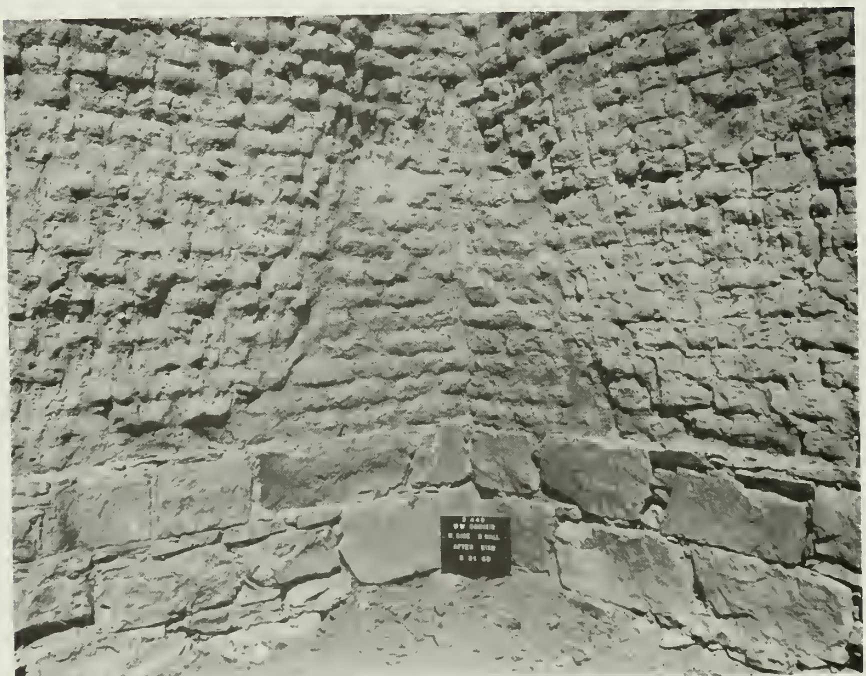


FIGURE 76. Building 3-440, southwest corner, after stabilization. Fort Union National Monument.

of 1/8" x 2" angle-iron. The rectangles formed were incorporated into the wall proper, by rebuilding this section with soil-cement brick up to and through the rectangles. (The upper sections of wall had eroded out, leaving the coping balanced on just a few inches of adobe.) Two large holes in the wall under the coping were also filled with soil-cement brick.

The free-standing sections of iron (including those portions which overlap the remainder of the vertical sections of the uprights) were further strengthened by welding together two lengths of 1/8" x 2" angle-iron so as to form square members. To these is welded a horizontal member of 1/8" x 2" angle-iron which is cupped over the top (east) edge of the coping, and the 1/8" x 2" strap iron hooks which cross the coping and extend down the west side about 6". The horizontal member under the coping on the east side of the north half of the wall was extended so as to pass under the coping on the south half. Again, it was secured by short lengths of 1/2" reinforcing rod which pass through the wall immediately under the coping, and are welded to the horizontal member on the west side of the wall and to the box members of the east. The rest of the framework was secured by ties through the wall, using 5 sections of 1/2" reinforcing rod to hold each vertical member except the short one over the window (where 3 were used).

Both halves of the framework in the coping-bearing wall are welded together through the abutting wall with sections of 1/2" reinforcing rod at the bottom, and 1/8" x 1/4" and 1/8" x 3/4" sections of angle-iron at the top. Those ties which cross the top of the abutting wall are welded to a historic iron bar which is imbedded in the abutting wall, and penetrates the coping-bearing wall. At one time the east end of the bar was secured by a vertical pin driven into the wall (this pin had to be replaced) and the west end was fitted with an S-shaped retaining plate. It will be necessary to place a new plate on the west end, but this has not yet been done.

To keep water from penetrating to the inside of the stabilized coping and supporting wall, a concrete cap (mixed 3 sand, 1 cement) 2 to 3" thick was placed over the top of the whole coping. The cap extends down over both edges the thickness of one brick. This extension was possible because the width of the top course of brick is less than that of the next-to-top course. When dry, the cement was painted with burnt sienna and raw umber in Exterior Stucco Finish (adobe) to render the cap less obvious.

To provide a better bond between metal, concrete and soil-cement all the angle-iron which was to be enclosed by the rebuilt portions of the wall or by refilling of the channels was first covered with metal lath. (Exposed sections of angle-iron were painted with red lead darkened with burnt sienna and raw umber.) Then all channels in the adobe wall were filled with colored soil-cement.

All holes and cracks in both sides of the west (coping-bearing) wall were pointed up with soil-cement, of the same mix and color as that used in the soil-cement brick and mortar in the chimneys of Officers' Row.

A gallon sample of Hydrocide SX was applied by brush to a meter-wide strip of the west side of the west wall. The strip extends from immediately above the top of the rock foundation to the top of the brick coping (west face only). The remainder of the coping (including the whole top surface) and adobe wall (both sides and ends) was sprayed with Dow Corning 129G Resin dissolved in xylene. The solution was applied, at about 30 pounds square-inch pressure, in sufficient quantity to produce a rundown of at least 6 inches.

East wall: Capped (see introduction for detailed explanation of technique). Sprayed with Dow Corning 772 diluted in water at a ratio 1 to 9.

FIRST SHEET

Fort Union National Monument. Date: *May 27, 1960; Building: 3-440;* Room: *441, 442, 443;* Wall (N. E. S. W): *NS.*

Architecture

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning,

etc.): *Contemporaneous with contiguous rooms. No evidence of burning. Single story.*

Floor (floor type, additional notes): Probably had wood floor.

Details (notes on doorways, lintels, etc.): *Eastern extremities of both walls missing.*

SECOND SHEET

Room No.: *3-440;* Date work started: *May 15, 1957;* Date work finished: *May 24, 1960;* Man days of labor: *ca. 43 1/2;* Cost of materials: *ca. $126.08;* Archeologist: *Rex L. Wilson;* Date: *May 27, 1960.*

Condition on date work started. Masonry: *Walls in fair condition. Need capping to prevent further deterioration due to penetration of moisture. Adobes missing from above several lintels. Large hole where south wall abuts west wing wall.*

Materials, construction, and technique in making repairs or accomplishing job: *North wall: Soil-cement adobes were used to fill all holes and niches eroded out below the cap which is also of soil-cement adobes.*

South wall: Adobes set in adobe mortar were used for all patchwork except for the cap proper which is soil-cement. Large hole filled with soil-cement adobes.

North and South walls: Sprayed with Dow Corning 772 diluted in water at a ratio of 1 to 9.

APPENDIX 2C

Realignment of Adobe Walls

The following records describe realignment and stabilization of leaning adobe walls, and also a method of bracing a wall by means of turnbuckle rods (figs. 77-92).

RUINS STABILIZATION RECORD FIRST SHEET

Fort Union National Monument. Date: May 3, 1960. Building: 3-450; Room: 451; Wall (N. S. E. W): NESW.

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning, etc.): *Contemporaneous with contiguous rooms. No evidence of burning. Single story.*

Floor (floor type; additional notes): *Probably had wood floor.*

Details (notes on doorways, lintels, etc.): *Most of east wall is made of stone; only upper portion is of adobe. West wall is the east wall of room 452.*

SECOND SHEET

Room No.: *3-451;* Date work started: *July 26, 1958;* Date work finished: *July 7, 1959;* Man days of labor: 57; Cost of materials: $256.56; Archeologist: *Rex L. Wilson;* Date: *May 3, 1960.*

Condition on date work started. Masonry: *Massive south wall bulging northward. Only extreme west end of north wall standing. East and west walls in good condition but all walls needed capping to prevent further deterioration from penetration of moisture. Small north wall section leaning northward several inches out of plumb.*

Materials, construction, and technique in making repairs or accomplishing job: *South wall: A portion of the south wall was realigned in order to prevent collapse. The section, near the east end of the wall, bowed to the north about 12" at the top. Four wooden forms were completed and put in place on the bulge, two on either side of the wall. They were lined with asphalt roofing felt, wired together through the wall with No. 9 black wire, and then the space between form and wall was packed with damp sand. Two mine roof jacks and one heavy-duty jack were used to move the wall. The jacks push against the wall by means of long sections of 2" pipe (mine roof jacks) and 4" x 4" timber (truck jack). After pushing the wall into plumb the jacketing was removed from both sides of the wall and stabilization was begun by placing six upright steel members, and two horizontal members of the same material, with a steel strap along the bottom seated upon the stone foundation. The wall's brick coping is being held in place by seven steel rods looped about it and welded to the steel members on the wall's north side. The steel on the north side of the wall is secured by rods through the wall that are held in place by short steel straps. A hole in the wall was filled with regular adobes, cracks were grouted, steel was covered with adobe, the coping was secured, and adobes were laid along the top of the wall preliminary to capping.*

North wall: Two deadmen holes, 2' x 4' x 22", were dug next to the joist footing wall inside the room. Two 44" lengths of 1/2" reinforcing rods

FIGURE 77. Building 3-450, Room 451, south side of south wall, before stabilization. Fort Union National Monument.

FIGURE 78. Building 3-450, Room 451, south side of south wall, during stabilization. Fort Union National Monument.

FIGURE 79. Building 3-450, Room 452, south side of south wall, before stabilization. Fort Union National Monument.

FIGURE 80. Building 3-450, Room 452, south side of south wall, after stabilization. Fort Union National Monument.

FIGURE 81. Building 3-450, Room 451, south side of south wall, after stabilization. Fort Union National Monument.

were welded perpendicular to 2' lengths of 2" x 2" angle-iron, and looped at the other ends. These were placed in the holes which were then filled with concrete, reinforced with heavy wire. The wall was then jacked into plumb with mine jacks. A 15' length of 1 1/2" x 1 1/2" angle-iron was placed horizontally against the outside of the wall, near the top just above the lintel. The angle-iron was held in place by long bolts made by welding 5/8" carriage bolts on one end of 44" lengths of 1/2" reinforcing rod; these same rods were looped on the other ends to accommodate the 4" steel cable that was then attached to the deadmen. Turnbuckles on the two 16' cables allow for tightening.

All walls: *Capped (see introduction for detailed explanation of technique). Sprayed with Dow Corning 772 diluted in water at a ratio of 1 to 9.*

FIRST SHEET

Fort Union National Monument. Date: *May 3, 1960*; Building: *3-450*; Room: *452*; Feature: *wing wall*; Wall (N. E. S. W.): *NS.*

Architecture

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning, etc.): *Contemporaneous with contiguous rooms. No evidence of burning. Stone-lined basement.*

Floor (floor type; additional notes): *Probably had wood floor.*

Details (notes on doorways, lintels, etc.): *Lintel timber missing from above one window. Adobes missing from above one window in south wall. East wall considered as west wall of room 451. Large dressed and semi-dressed stones missing from the upper areas of the west and north basement walls.*

SECOND SHEET

Room No.: *3-452*; Date work started: *June 30, 1958*; Date work finished: *May 6, 1960*; Man days of labor: *ca. 21 3/4*; Cost of materials: *ca. $61.40.* Archeologist: *Rex L. Wilson*; Date: *May 3, 1960.*

Condition on date work started. Masonry: *South wall in good condition. Brick coping on*

southwest wing wall needed reinforcing. Cracks needed grouting. Very low, short north wall remains. Only stub remains of west wall. All walls needed capping to prevent further deterioration due to penetration of moisture.

Materials, construction, and technique in making repairs or accomplishing job: *Wing wall: A 2" x 1/8" angle-iron collar was placed immediately below the coping on all four sides so as to support the outermost courses of brick. It was held in place by four lengths of 3/8" reinforcing rod which penetrate the wall and are welded to the collar. The coping is in good shape, as is its supporting wall, so the work is to prevent further deterioration. A cement cap was poured to protect the top of the coping. It is about 2" deep above the middle of the coping, and slightly less above the edges. The cement was colored with burnt sienna and raw umber in exterior stucco to approximate the historic brick color. The angle-iron collar was than covered with metal lath and hard-packed, colored soil-cement. To render less visible the fairly smooth (although roughened) plaster, "blobs" of soil-cement were thrown on it. Although some of these may erode off, any that remain effectively break up the reflection of light off the plaster. Sprayed with Dow Corning 772 diluted in water at a ratio of 1 to 9.*

North and south walls: Capped (see introduction for detailed explanation of technique) and grouted with soil-cement. Missing adobes above windows were replaced and lintel timbers were replaced where missing. Sprayed with Dow Corning 772 diluted in water at a ratio of 1 to 9.

Missing stones from the upper basement walls were reset in cement mortar to the original height of the wall on the west side and to slightly less than the original height on the north side.

FIGURE 82. Building 3-450, Room 451, north side of south wall, before stabilization. Fort Union National Monument.

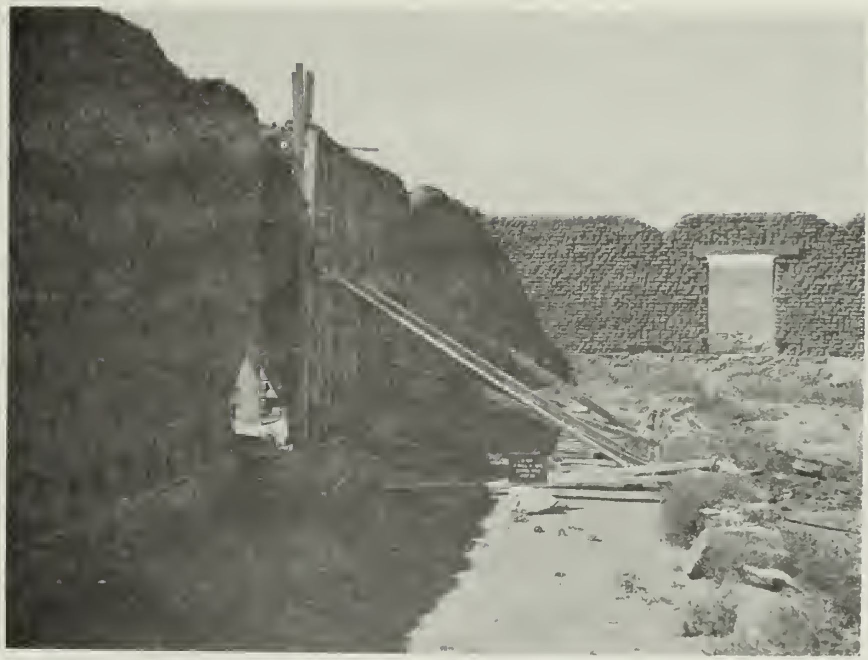


FIGURE 83. Building 3-450, Room 451, north side of south wall, during stabilization. Fort Union National Monument.

FIGURE 84. Building 3-450, Room 451, north side of south wall, during stabilization. Fort Union National Monument.

FIGURE 85. Building 3-450, Room 451, north side of south wall, after stabilization. Fort Union National Monument.

FIGURE 86. Building 3-450, Room 451, east side of west wall, before stabilization. Fort Union National Monument.

FIGURE 87. Building 3-450, Room 451, east side of west wall, after stabilization. Fort Union National Monument.

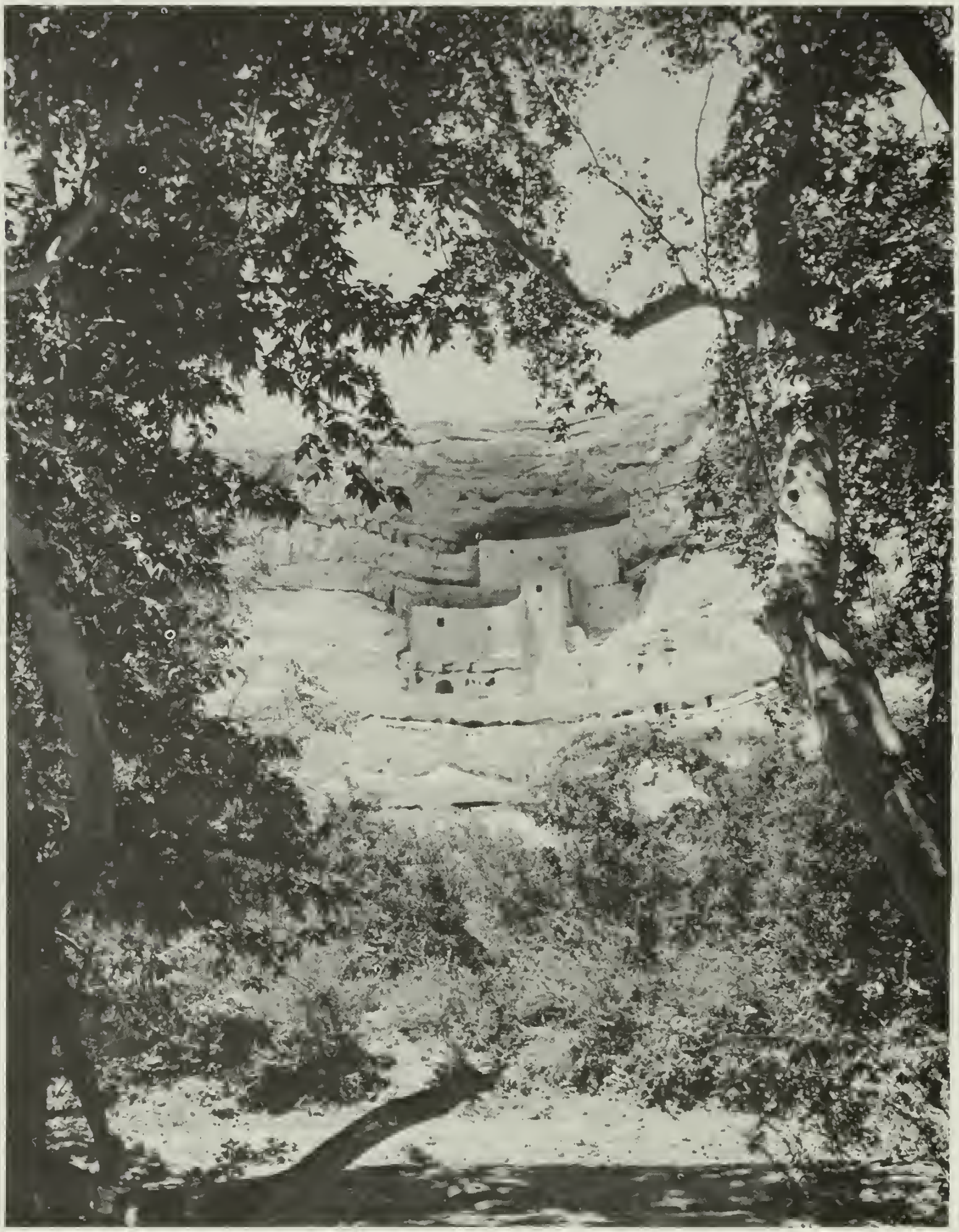
FIGURE 88. Building 3-450, Room 451, north side of north wall, before stabilization. Fort Union National Monument.

FIGURE 89. Building 3-450, Room 451, south side of north wall, before stabilization. Fort Union National Monument.

FIGURE 90. Building 3-450, Room 451, south side of north wall, during stabilization. Fort Union National Monument.

FIGURE 91. Building 3-450, Room 451, south side of north wall, after stabilization. Fort Union National Monument.

FIGURE 92. Building 3-450, Room 451, north side of north wall, after stabilization. Fort Union National Monument.



Montezuma Castle National Monument, Camp Verde, Arizona. The structure was built and occupied during the period A.D. 1100-1400 by a people of Pueblean ancestry. Only a few breaks in the upper parapet wall and the roof of the square tower room have been repaired with original materials. By 1957, increasingly heavy visitor impact began to weaken the structure noticeably, at which time it was closed to public viewing. The ruin is seen today by visitors from the trail below where a cutaway scale model enhances the interpretive story.

APPENDIX 2D

Stabilization of Weakened Chimneys

The following records describe techniques for the stabilization of broken or weakened historic chimneys (figs. 93-98).

RUINS STABILIZATION RECORD FIRST SHEET

Fort Union National Monument. Date: *April 22, 1960;* Building: *6-160;* Room; *163;* Wall (N. E. S. W): *NESW.*

Architecture

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning, etc.): *Contemporaneous with contiguous rooms. No evidence of burning. Single story.*

Floor (floor type; additional notes): *No floor remains. Joist indications suggest wood floor.*

Details (notes on doorways, lintels, etc.): *Chimney and fire-place in east wall. North wall is south wall of rooms 161 and 162. Fireplace badly weakened by missing bricks. Loose bricks in chimney remnant. Brick hearth missing.*

SECOND SHEET

Room No.: *6-163;* Date work started: *June 29, 1959;* Date work finished: *Oct. 23, 1959;* Man days of labor: *14 3/4;* Cost of materials: *$52.62;* Archeologist: *Rex L. Wilson;* Date: *April 22, 1960.*

Condition on date work started. Masonry: *Nearly all of east wall missing except for flue. Many adobes missing from all sides of adobe flue. North wall in good condition. Lintels missing from window in south wall. West wall in good condition.*

Materials, construction, and technique in making repairs or accomplishing job: *East wall: Missing foundation stones replaced in fireplace, brick hearth rebuilt with historic brick, missing fireplace brick reset in soil-cement mortar. Missing adobes were replaced in the north, east, and south sides of the flue. The small chimney remnant stabilized by resetting loose bricks in soil-cement mortar and replacing several missing bricks.*

South wall: The east end of the wall was rebuilt with regular adobes in order to support the remaining original wall.

All walls: Capped. Sprayed with Dow Corning 772 diluted in water at a ratio of 1 to 9.

FIGURE 93. Building 6-160, Room 163, fireplace in east wall, before stabilization. Fort Union National Monument.

FIGURE 94. Building 6-160, Room 163, fireplace in east wall, during stabilization. Historic bricks are being reset in soil-cement mortar. Fort Union National Monument.

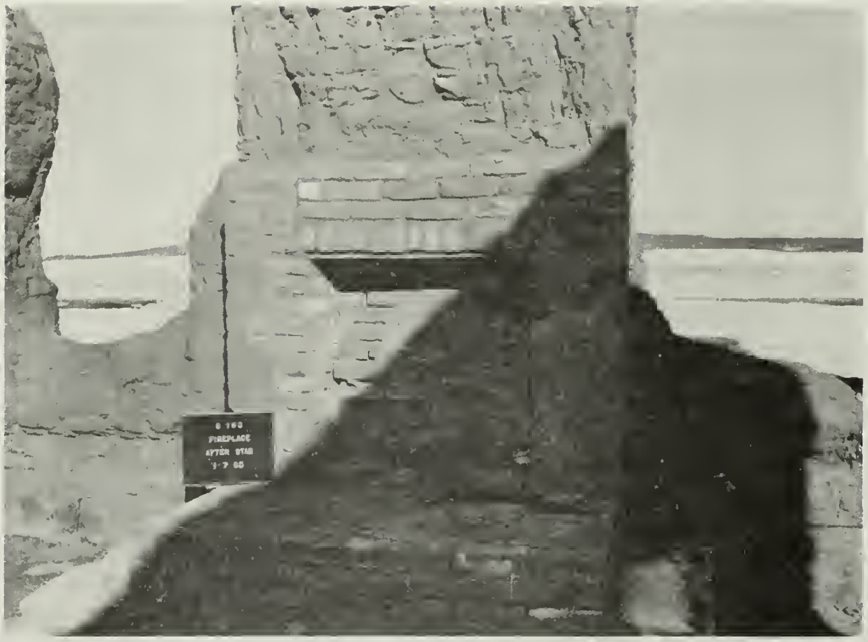


FIGURE 95. Building 6-160, Room 163, fireplace in east wall, after stabilization. Soil-cement mortar used to reset bricks was brushed to prevent shine. Fort Union National Monument.

FIGURE 96. Building 6-160, east side of east wall, before stabilization. Fort Union National Monument.

FIGURE 97. Building 6-160, Room 163, flue and chimney in east wall, during stabilization. Soil adobes are being laid to replace those that had fallen away. Fort Union National Monument.

FIGURE 98. Building 6-160, Room 163, flue and chimney in east wall, during stabilization. Fort Union National Monument.

A small sector of the plaza and northwest corner of West Ruin, Aztec Ruins National Monument, Aztec, New Mexico. Earl H. Morris restored the Great Kiva in 1934. The two most important preservational considerations involved are (1) the erosion and rotting of soft sandstone masonry, particularly the basal courses of walls, hastened by capillary action and, at various times in the past, by improper surface drainage, and (2) the preservation of 21 prehistoric ceilings and the maintenance of modern, concealed roofs which protect them.

APPENDIX 2E

Stabilization of Stone Masonry

The following records contain detailed ruins stabilization information for Kin Ya-a, a classic site in Chaco Canyon National Monument. Techniques for stabilizing prehistoric stone masonry are included (figs. 99-119).

RUINS STABILIZATION RECORD FIRST SHEET

Chaco Canyon National Monument. Date: Sept.-Oct., 1956. Ruin: Kin Ya-a. Kiva: Tower; Wall (N. S. E. W.): (NESW).

Architecture

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning, etc.): *This is a circular kiva set within four square retaining walls, located along the north wall of the house mound and approximately in the center. The Tower Kiva forms the nucleus for the pueblo. This unique round tower within a square one is impressive because portions of the north and east enclosing walls stand 4 stories high. On both the east and west sides of the tower there are at least 3 tiers of rooms. The main house block, however, is to the south and is quite mounded over but contains perhaps 4-5 tiers of rooms. All exposed masonry appears to be of the same type, indicating a single construction period. The third and fourth stories of the inner, circular kiva burned.*

Floor (floor type; additional notes): *Site is not excavated and there is no data on this.*

Roof (roof type; additional notes): No data.

Details (notes on doorways, lintels, etc.): *See additional pages for detailed notes pertaining to condition description, materials, construction, etc., with respect to each individual wall of the kiva.*

SECOND SHEET

Date: *Sept.-Oct., 1956;* Ruin: *Kin Ya-a;* Kiva: *Tower;* Wall (N. S. E. W.): *NSEW.* Personnel of party on job: *R. Richert and six Navajos.*

Justification: *The fragile tower Kiva remnant, a unique architectural development of the Chaco Culture, was reinforced and repaired to preserve it in nearly an "as found and as is" condition as possible and in such manner which will not impair any future, proposed excavations.*

References: *The site is unexcavated and most references are only general. However, a listing of tree-ring dates appears in the following publication: Smiley, T. L., A Summary of Tree-Ring Dates from Some Southwestern Archeological Sites. University of Arizona Bulletin, vol. XXII, no. 4, Oct. 1951. Laboratory Bulletin of Tree-Ring Research, No. 5, Tucson, Arizona.*

Condition, description: *The Tower Kiva, north wall exterior. In profile this is an L-shaped wall remnant, the vertical arm of the L forming a narrow section 8' wide, beginning at the second story and tapering at the top to an area only one stone wide. It is four stories high, measuring 32' 10" from the base at present surface level to the top stone. The exposed base of the wall at the*

top of the debris slope is 4' 6" higher than the surrounding ground level; hence the assumed base of the wall is at least that much lower, making the wall 37' 4" high, conservatively.

Three beam stubs are embedded in the masonry in the north-south direction, the ends projecting slightly beyond the exterior facing. They are nearly in line one above the other, at the first, second, and third stories. They are not roof supports as they extend into the thick kiva corner and stop there. It would appear that they were either reinforcing ties for the kiva corner, or their projecting ends served as a support for some sort of balcony, or perhaps scaffolding along the outside for construction of this high wall.

At the first story level, in a horizontal line with, and to the west of the lower beam stub mentioned in the preceding paragraph are two square openings. These formerly held beams as they still retain the molds. Spaced at 5' 8" intervals with the first beam, they may have served as projections to hold a scaffolding or catwalk. About two rows of stones beneath, and closest to west opening, is a third square opening which is a ventilator and largest of the three (15" wide, 16" high). In cleaning the top of the wall section above these openings, there was found the lower part of a fourth: a T-shaped ventilator 12" wide at the base and 16" in width above the shoulder. The two ventilators in this wall were open to the kiva.

Beginning at the second story level, the wall is inset 3" to the south; and at the second story elevation it is inset 6", presumably to insure better balance for such a high wall.

At a height of 39" above present surface level, the exterior facing contains one row of extraordinarily large, oblong blocks, the largest measuring 51" long, 6 to 9" thick, and 9" wide or deep. As a rule, the stones in the lower story are thicker and larger than those in the upper three stories. The north wall exterior is further characterized by considerable spalls between the courses of large stone blocks. This straight wall averages 22" wide. For the most part it is faced on both sides, and has a core of smaller flat stones with irregular edges set in thick amounts of soil mortar.

FIGURE 99. General view of Kin Ya-a from the north. Tower Kiva occupies central part, flanked by house mounds on each side. Ruins stabilization work and supply area in the foreground.

FIGURE 100. Close-up of north wall, Tower Kiva.

FIGURE 101. Tower Kiva, north wall exterior. Note large hole at base, and eroded insets (arrows) where second, third and fourth stories were slightly stepped back.

FIGURE 102. Hole at base, square openings (the two upper held beams, the lower was a ventilator) and insets repaired and wall stubs capped. Beam stub at left and two beam holes in line above (arrows) either represent reinforcing ties for kiva corner or supports for some sort of prehistoric scaffolding used in construction or a balcony.

Considering its spectacular height, the wall is in good condition, but must be strengthened by repairing, reinforcing and capping to preserve its present condition.

The Tower Kiva, north wall interior. (For illustrations covering work on north and east wall interiors see figures 103-111.) The north wall interior contains the north arc of the kiva. The kiva wall is not perfectly circular as there are at least two somewhat angular surfaces evident in the facing where the prehistoric builders were unable to make the square or oblong stones form a circular surface. The kiva wall at this north side has two eccentric ledges or benches. The lower bench varies from 0" to 20" above fill level and varies 0" in width at the east where it merges with the facing to 27" wide at the north side. Another short ledge is 7 1/2" above the lower and extends for a distance of only 67" along the north wall. Whether these very narrow ledges were ceremonial or utilitarian is unknown. The

FIGURE 103. General view of northeast interior of Tower Kiva at start of project. The circular wall is stepped back or inset at two points: (1) at narrow ledge or bench where workman is beginning repairs, and (2) where facing is gone, exposing core (arrow).

kiva must have been extremely deep, as the wall at the northeast corner within the kiva measures 19' above present fill line, and it is possible that this deep chamber had several floors and ceilings. The eccentric ledges may have supported crossbeams for these ceilings. Excavation of the interior of this interesting structure might provide the answers to some questions regarding an aberrant architectural form.

Materials, construction, etc.: *The Tower Kiva, north wall exterior. The high, sloping east and west wall stubs were capped, extending the east stub slightly eastward to provide a short but strong buttress section. Two integral members were placed in the west stub where it rises vertically, beginning at the second story level, the members extending to those rising from the east wall. The second and third story ledges or insets were repaired. The several openings including the two square beam holes, and the ventilator beneath them, and the beam holes at the east side were all repaired. The large hole at the base of the wall was filled with repair masonry in cement, the rough interior core being set in cement and the face stones laid in matching tinted cement. Following the above work, the entire wall face was grouted, pointed, and respalled. It was necessary to reset a few loose stones here and there in the facing.*

The two eccentric, offset ledges along the north arc just above fill line were repaired. The lower half of a T-shaped ventilator in the center of the wall between the second and third story levels was repaired. East and west stubs were reinforced with paired integral members in connection with work on north wall exterior, already described. Within the upper kiva wall (includes the upper, spire-like fragment) considerable face stones were reset, and, where core was exposed, this was reset and pointed with soil-mortar. At the very top spire fragment itself, paired T-shaped integral members were installed.

The Tower Kiva, east wall, exterior. This wall rises at the north end to the same height as the north wall against which it is abutted. Parts of four stories are clearly visible as indicated by

three rows of savino sockets. In profile, the wall top slopes up from south to north, to the spire in wavy fashion. In the first floor ceiling level there are 23 savino sockets; in the second story ceiling, 13 savino sockets remain, seven of which still contain stubs. In the third story ceiling there are four savino stubs. This exterior or east side of the wall formed the west side of the first room adjacent to the tower kiva on the east. Facing contrasts sharply with that of north wall. Whereas the north wall was composed of nice oblong blocks dressed on one side, and rather large as a rule, the face stones in the east walls are generally smaller, less well selected and shaped.

The wall was in rather poor condition. It had several vertical cracks, one of severe proportions. The most serious condition, however, was a large hole extending through the midsection at first story level where eroding beam sockets were producing an ever increasing opening.

East wall, interior. The two narrow benches mentioned in connection with north wall interior merge with the wall, i. e., disappear along the east wall. The fill is banked higher along this wall and the south wall than elsewhere. The hole in midsection extending through the wall, caused by breakdown of beam sockets on the exterior side, is larger on this side. Broken and missing face stones need replacement, rough exposed core in upper sections should be reset, and the vertical wall stub forming northeast corner reinforced.

Materials, construction, etc.: *The Tower Kiva, east wall, exterior. The three rows of savinos and/or savino sockets, the vertical cracks, and the large hole at midsection were repaired. Entire facing was respalled, grouted and pointed.*

East wall, interior. The south half of the top was horizontally capped. The vertical or sharply sloping north half was reinforced with paired integral members which arch up and cross over near the top spire and are joined with those from the north wall. Circular wall facing grouted and pointed and stones reset as needed. Large hole in center at fill line patched.

Condition, description: *The Tower Kiva, south wall. Fill was banked up all along the south wall and the top was obscured at central portion.*

FIGURE 104. Another view showing general condition of lower part of interior.

Thick core was exposed at both southeast and southwest corners. The remaining portion of circular kiva wall is lower at this point than along the other three quadrants. This area needs cleaning to obtain a base on which to perform repair work in order to preserve and show original wall outlines.

Materials, construction, etc.: *The Tower Kiva, south wall. The top was cleaned to reveal the straight, south wall enclosing the kiva. The thick kiva corners and the straight enclosing wall were capped. The exposed facing of the interior, circular wall was gone over by grouting, pointing and respalling.*

Condition, description: *The Tower Kiva, west wall. The straight wall here encloses the west portion of the circular kiva. The kiva corners enclosed are exposed to a height of 6' above present fill line. Exterior wall facing is either missing or pretty well covered by fill. A 4' thick section of rough core is exposed at the northwest corner. At the center of the west wall and level with fill both inside and outside the room, is a large U-shaped opening probably caused by breakdown to timbers embedded in this wall which provided support for the ceiling in the room to the west. The wall core at this U-shaped opening is thin, loose, and porous and is deteriorating rapidly. Visitors who climb to the Tower Kiva enter the circular chamber at this point. Note: visitation to this little known area may be infrequent but there were three or four visitor groups at the ruins during our project within a period of one month.*

Materials, construction, etc.: *The Tower Kiva, west wall. Both northwest and southwest kiva corners were cleared of surface debris, and capped. The northwest outside corner was excavated until good foundation was encountered, and then the exterior facing was reset to a depth of 18 to 20 courses at the north end, and to a depth of 4 to 5 courses at the south end. The exposed core and veneer around the U-shaped opening in the central section was reset (figs. 115-117).*

Figures 118 and 119 illustrate some work in progress on the Tower Kiva. Note the use and adaptability of tubular steel scaffolding.

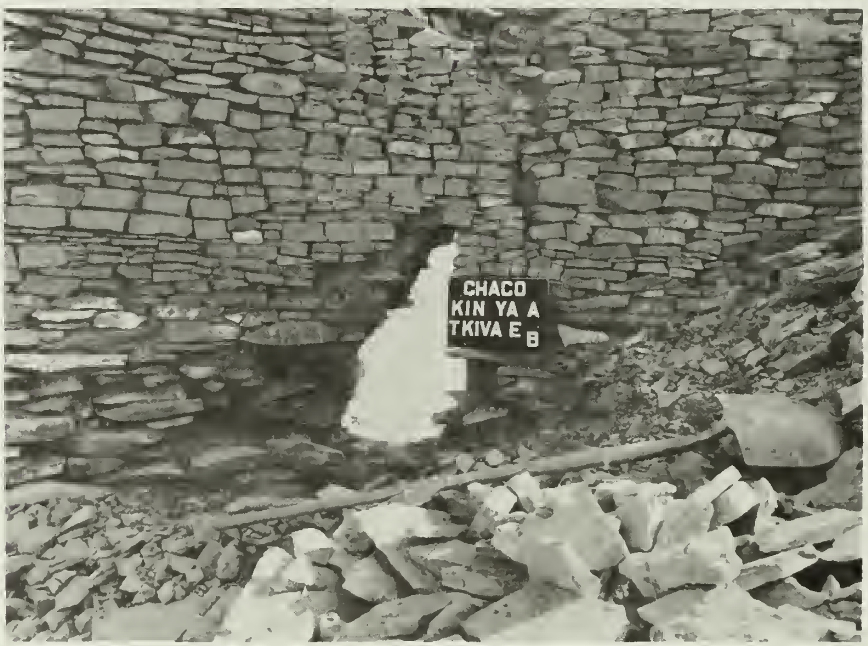


FIGURE 105. Detail of hole in Tower Kiva caused by breakdown of savino sockets. The beams for the sockets extended part way into this wall from the opposite side, and originally supported the ceiling of the adjacent room.

FIGURE 106. Lower portion of Tower Kiva, north and east segments, after stabilization. Offset ledges repaired, holes filled with repair masonry, facing reset (arrows A), top capped and inset core (arrow B) grouted.

FIGURE 107. Tower Kiva, interior northeast corner, during installation of integral members to strengthen the highest wall section.

FIGURE 108. Upper portion of Tower Kiva, northeast corner interior, after the integral members were anchored in masonry.

FIGURE 109. Beginning the vertical, reinforced capping (arrows).

FIGURE 110. Integral members in the form of a T were installed in this top fragment of core másonry after the lower wall section had been strengthened to that point.

FIGURE 112. Tower Kiva, east wall exterior at juncture with north wall stub (at sign). Note the vertical cracks, eroded savino sockets (arrows) and loose, fragile spire. Portions of 4 stories are visible.

FIGURE 111. The wall at completion of stabilization. The wall is considerably strengthened and tightened, without a serious or objectionable alteration of the original profile.

FIGURE 113. View of Tower Kiva showing vertical cap.

FIGURE 114. View of Tower Kiva showing north wall stub buttressed, cracks repaired, savino sockets remolded, and facing grouted.

FIGURE 115. Tower Kiva, northwest corner.

FIGURE 116. North wall stub capped (arrows A), lower portion of west wall facing reset (B), and exposed portion of thick core grouted (C).

FIGURE 117. Tower Kiva, west wall. This fragmentary section of the square tower enclosing a round one was repaired by resetting the facing (arrow A), capping and grouting the thick core (B).

FIGURE 118. Work on the highest portion of the tower. The scaffolding completely surrounded the structure. To provide maximum safety for the workmen, the three sets of scaffolding were anchored at the bases and across the top and through midsections.

FIGURE 119. Tower Kiva. Scaffolding was anchored on firm and level bases built of heavy timbers.

An interior view of Betatakin Ruin. The three major sites of Navajo National Monument—Betatakin, Keet Seel, and Inscription House—are well protected from the natural elements, except for rare internal disturbances such as blocks of sandstone breaking from the cave roofs. The major problems at Navajo are the protection and maintenance of scenic and fragile cliff dwellings, and the control of visitors.

APPENDIX 2F

Stabilizing Stone Masonry Walls

The records below contain stabilization information for Talus Unit No. 1, a small classic ruin in Chaco Canyon National Monument. They describe a method for stabilizing a distorted, prehistoric stone masonry wall (figs. 120-123).

RUINS STABILIZATION RECORD FIRST SHEET

Chaco Canyon National Monument. Date: *July 27, 1959;* Ruin: *Talus Unit No. 1;* Room *27;* Wall (N. S. E. W.): *NESW.* Personnel on job: *Joel Shiner and eight Navajos.* References to publications and justifications for job: *Unpublished notes by Paul Walter in 1933, and Margaret S. Woods in 1934. Their work was accomplished through the School of American Research.*

Architecture

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning, etc.: *Long rectangular room of two stories; masonry is Type II (tiered blocks and spalls). It is one of a half-dozen rooms which are in two rows.*

Floor (floor type; additional notes): No floor present now.

Roof (roof type; additional notes): *Ceiling of first floor shown by a ledge and by numerous beam holes. Roof of second floor is gone.*

Details (notes on doorways, lintels, etc.): *Doorways in south wall on first and second stories.*

SECOND SHEET

Ruin: Talus Unit No. 1; Date: July 27, 1959; Wall (N. S. E. W.): NSEW. Condition on date when work started:

Ancient masonry: *North wall above the ledge leans precariously into the room. East and west walls have eroded and are loose at the top. Footings of all four walls are undercut by erosion. Beam holes are eroding where beams have decayed.*

Repair or reconstruction previous to this work: *None.*

Materials, construction, and technique in making repairs or accomplishing job: *Part of the center section of the leaning wall was removed. A horizontal slab of steel-reinforced concrete was poured so as to abut against the junction on the partition walls. Steel rods were fastened through both wall and slab with turnbuckles between. Using the turnbuckles, the wall was pulled back to nearly vertical position. The stones removed were then replaced in tinted cement. East and west walls had already been patched and strongly capped to bear the load. New stones were set in cement around the wall footings. The beam holes were patched in tinted cement.*

Date work started: *July 29, 1959;* Date work finished: *August 14, 1959;* Work authorized by: *Roland Richert, Archeologist.*

FIGURE 120. The wall between Rooms 27 and 28, Talus Unit No. 1, was distorted and pushed out of line by pressure of fill, often damp, at left. Arrow shows direction of force. The purpose of the stabilization was to strengthen the wall against the pressure.

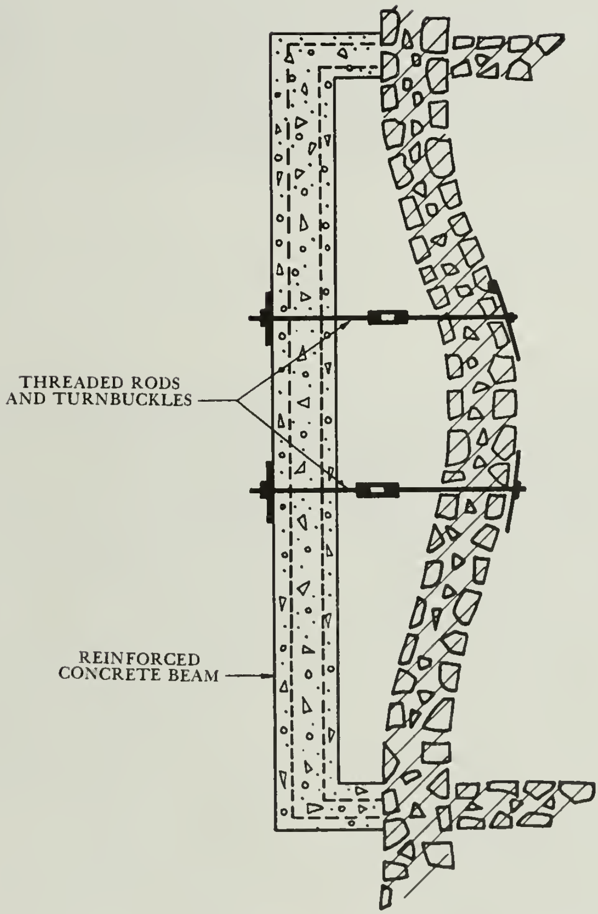


FIGURE 121. Plan of reinforced beam to realign and hold north wall, Room 27, Talus Unit No. 1 (not to scale).

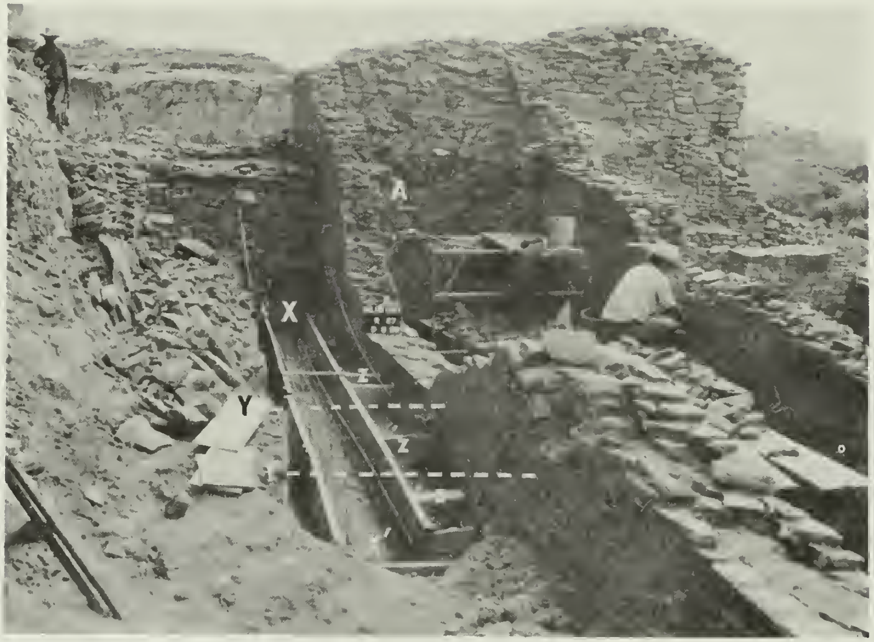


FIGURE 122. Construction of concrete beam shown in figure 121. The frame is complete and reinforcing rods are in place. X—X1- beam, Y—location of threaded rods and turnbuckles, Z—temporary braces. The ends of the beam bear against the wall at each side of the bulged area at points where the wall is braced against movement by partition walls. That at the east shown as A.

FIGURE 123. This wall in Talus Unit No. 1 has been pulled back into line; the capping is straightened up. The concrete beam dug into Room 28 is covered and the surface of this room (arrows) is graded to carry surface runoff away from the damaged wall.

APPENDIX 2G

Cliff Dwelling Stabilization

The following are stabilization records for Site NA 333, a four-room cliff dwelling in Walnut Canyon National Monument (figs. 124-126).

RUINS STABILIZATION RECORD FIRST SHEET

Walnut Canyon National Monument. Date: *Oct., 1955;* Room: *1;* Wall (NESW): *NSE.* Personnel on job: *G. Vivian and R. Richert.*

Architecture

Orientation, plan and type (situation, evidence of additional stories, period of construction relative to surrounding rooms, evidence of burning, etc.): *This is the southermost of four contiguous rooms comprising NA 333. Nearly square in plan. Wall junctures indicate that it is at least older than Room 2, but not as old as Rooms 3 and 4. Sequence of construction was probably as follows: Rooms 3 and 4 built as a unit, followed by Room 1 at the south end of the cave, and leaving an open gap as a work area between which was subsequently walled across to form Room 2.*

Floor (floor type; additional notes): *Unexcavated.*

Roof (roof type; additional notes): *Cave.*

Details (notes on doorways, lintels, etc.): *Doorway in center of east wall. Lintels are missing and the area above the door is broken into a V shape. Door is characterized by a high sill.*

SECOND SHEET

Room: 1; Date work started: Oct. 12, 1955; Date work finished: Oct. 13, 1955; Work authorized by: G. Vivian, Archeologist.

Condition on date when work started. *Ancient masonry: Fair. North Wall: In poorest condition. A large hole beginning at foundation and extending to midsection caused by pot hunters has made this wall extremely weak, and collapsed all of the eastern third except a fragile corner one stone wide. East Wall: Good except for eroded foundation, and the lower third of southeast corner which has collapsed. The V-shaped hole over doorway needs grouting on the north side.*

Repair or reconstruction previous to this work: None.

Materials, construction, and technique in making repairs or accomplishing job: *North Wall: The large hole measuring 3' x 4' was filled with repair masonry to save the upper section, and the northeast corner was buttressed also to preserve it. Repair work stained with black mortar color to match original.*

East Wall: Entire foundation one stone high was grouted and pointed. The south wall also had a few small holes along the foundation row where original soil-mortar had eroded and these were filled. Sill and wall area below door grouted and pointed.

FIGURE 124. Cans of water and large bucket of stabilized mortar suspended from carrier and riding across canyon to the project. (Walnut Canyon National Monument)

FIGURE 125. Room 1, east exposure, before replacement of fallen corner. (Walnut Canyon National Monument)

FIGURE 126. Room 1, east exposure, after replacement of fallen corner. The deeply eroded wall base was grouted, and the area above the doorway was partially reset. (Walnut Canyon National Monument)

APPENDIX 3

Executive Order 11593: Protection and Enhancement of the Cultural Environment

By virtue of the authority vested in me as President of the United States and in furtherance of the purposes and policies of the National Environmental Policy Act of 1969 (83 Stat. 852, 42 U. S. C. 4321 et seq.), the National Historic Preservation Act of 1966 (80 Stat. 915, 16 U. S. C. 470 et seq.), The Historic Sites Act of 1935 (49 Stat. 666, 16 U. S. C. 461 et seq.), and the Antiquities Act of 1906 (34 Stat. 225, 16 U. S. C. 431 et seq.), it is ordered as follows:

Section 1. Policy. The Federal Government shall provide leadership in preserving, restoring and maintaining the historic and cultural environment of the Nation. Agencies of the executive branch of the Government (hereinafter referred to as "Federal agencies") shall (1) administer the cultural properties under their control in a spirit of stewardship and trusteeship for future generations, (2) initiate measures necessary to direct their policies, plans and programs in such a way that federally owned sites, structures, and objects of historical, architectural or archaeological significance are preserved, restored and maintained for the inspiration and benefit of the people, and (3), in consultation with the Advisory Council on Historic Preservation (16 U. S. C. 470i), institute procedures to assure that Federal plans and programs contribute to the preservation and enhancement of non-federally owned sites, structures and objects of historical, architectural or archeological significance.

Sec. 2. Responsibilities of Federal agencies. Consonant with the provisions of the acts cited in the first paragraph of this order, the heads of Federal agencies shall:

(a) no later than July 1, 1973, with the advice of the Secretary of the Interior, and in cooperation with the liaison officer for historic preservation for the State or territory involved, locate, inventory, and nominate to the Secretary of the Interior all sites, buildings, districts, and objects under their jurisdiction or control that appear to qualify for listing on the National Register of Historic Places.

(b) exercise caution during the interim period until inventories and evaluations required by subsection (a) are completed to assure that any federally owned property that might qualify for nomination is not inadvertently transferred, sold, demolished or substantially altered. The agency head shall refer any questionable actions to the Secretary of the Interior for an opinion respecting the property's eligibility for inclusion on the National Register of Historic Places. The Secretary shall consult with the liaison officer for historic preservation for the State or territory involved in arriving at his opinion. Where, after a reasonable period in which to review and evaluate the property, the Secretary determines that the property is likely to meet the criteria prescribed for listing on the National Register of Historic Places, the Federal agency head shall reconsider the proposal in light of national environmental and preservation policy. Where, after such reconsideration, the Federal agency head

proposes to transfer, sell, demolish or substantially alter the property he shall not act with respect to the property until the Advisory Council on Historic Preservation shall have been provided an opportunity to comment on the proposal.

(c) initiate measures to assure that whereas a result of Federal action or assistance a property listed on the National Register of Historic Places is to be substantially altered or demolished, timely steps be taken to make or have made records, including measured drawings, photographs and maps, of the property, and that copy of such records then be deposited in the Library of Congress as part of the Historic American Buildings Survey or Historic American Engineering Record for future use and reference. Agencies may call on the Department of the Interior for advice and technical assistance in the completion of the above records.

(d) initiate measures and procedures to provide for the maintenance, through preservation, rehabilitation, or restoration, of federally owned and registered sites at professional standards prescribed by the Secretary of the Interior.

(e) submit procedures required pursuant to subsection (d) to the Secretary of the Interior and to the Advisory Council on Historic Preservation no later than January 1, 1972, and annually thereafter, for review and comment.

(f) cooperate with purchasers and transferees of a property listed on the National Register of Historic Places in the development of viable plans to use such property in a manner compatible with preservation objectives and which does not result in an unreasonable economic burden to public or private interests.

Sec. 3. Responsibilities of the Secretary of the Interior. The Secretary of the Interior shall:

(a) encourage State and local historic preservation officials to evaluate and survey federally owned historic properties and, where appropriate, to nominate such properties for listing on the National Register of Historic Places.

(b) develop criteria and procedures to be applied by Federal agencies in the reviews and nominations required by section 2 (a). Such criteria and procedures shall be developed in consultation with the affected agencies.

(c) expedite action upon nominations to the National Register of Historic Places concerning federally owned properties proposed for sale, transfer, demolition or substantial alteration.

(d) encourage State and Territorial liaison officers for historic preservation to furnish information upon request to Federal agencies regarding their properties which have been evaluated with respect to historic, architectural or archaeological significance and which as a result of such evaluations have not been found suitable for listing on the National Register of Historic Places.

(e) develop and make available to Federal agencies and State and local government information concerning professional methods and techniques for preserving, improving, restoring and maintaining historic properties.

(f) advise Federal agencies in the evaluation, identification, preservation, improvement, restoration and maintenance of historic properties.

(g) review and evaluate the plans of transferees of surplus Federal properties transferred for historic monument purposes to assure that the historic character of such properties is preserved in rehabilitation, restoration, improvement, maintenance and repair of such properties.

(h) review and comment upon Federal agency procedures submitted pursuant to section 2(c) of this order.

Richard Nixon

The White House,
May 13, 1971

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